BRUSH

OPERATING INSTRUCTIONS

amplifier
model RD 5612 00

This instruction book applies to
Model RD 5612 00 Serial No. ______________ and above

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■ If any fault develops

1. Notify the nearest factory branch service station, address on the next page, giving full details of the difficulty, and include the model number, type number and serial number. Upon receipt of this information, we will give you service instructions or issue a material return authorization card.

2. You may request any necessary instrument packaging by telling us what cartons you need. These will be sent to you no charge.

3. Upon receipt of shipping instructions, forward the instrument prepaid, and repairs will be made at the factory. If requested, an estimate of the charges will be made before the work begins, provided the instrument is not covered by the warranty.

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WARRANTY

Each instrument manufactured by Brush Instruments, Division of Clevite Corporation, is warranted to be free from defects in material and workmanship and to operate in accordance with the published specifications when used with the recommended Brush associate equipment and with Brush chart paper. Liability under this warranty is limited to servicing or adjusting any instrument returned to a factory branch service station for that purpose and to replacing any defective parts thereof except tubes, fuses, and batteries.

This warranty is effective for one year after delivery to the original purchaser. When the instrument is returned transportation charges are to be prepaid by the original purchaser. If defective operation has been caused by misuse or abnormal conditions of operation, repairs will be billed at our current rate. In this case an estimate will be submitted before work is started.

SUPPLIES AND SERVICE

Brush Instruments factory branch offices and service stations:

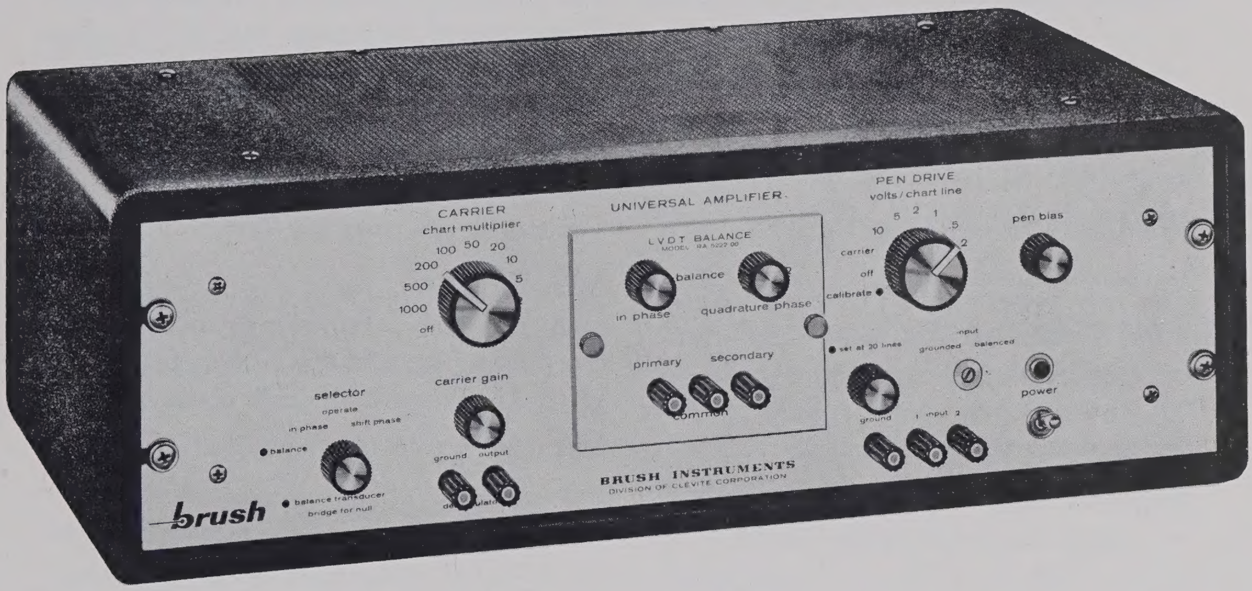
CLEVELAND
Mid-West
3405 Perkins Avenue
Cleveland 14, Ohio
Phone: ENdicott 1-3315

LOS ANGELES
West Coast
1960 So. La Cienega Blvd.
Los Angeles 34, California
Phone: TExas 0-7517

ARLINGTON
East Coast
561 - 23rd St., South
Arlington 2, Virginia
Phone: OTis 4-5912

BOSTON
New England
677 Worcester Street
Natick, Massachusetts
Phone: OLympic 3-8850

UNIVERSAL AMPLIFIER MODEL RD 5612 00



Universal Amplifier Model RD 5612 00 with LVDT Balance Model RA 5222 00 in Portable Case Model RA 1105 30.

The Universal Amplifier Model RD 5612 00 is both a high gain carrier amplifier and a medium gain d.c. amplifier. The unit is designed primarily for operation with resistive and reactive transducers, and may be ordered with the Bridge Balance Model RA 5212 00 or the LVDT Balance Model RA 5222 00. A balance box is essential to the operation of the carrier section of the amplifier, while the d.c. section is complete in itself.

As a carrier amplifier with the Bridge Balance Model RA 5212 00, the Universal Amplifier can be used with strain gages and variable reluctance transducers, with resistance values from 50 to 5000 ohms.

As a carrier amplifier with the LVDT Balance Model RA 5222 00, the Universal Amplifier can be used with linear variable differential transformers or other inductive transducers.

Balance boxes for use with specific variable reluctance transducers may be obtained on special order from Brush Instruments, Division of Clevite Corporation.

As a d.c. amplifier the unit is capable, at maximum sensitivity, of deflecting a Brush oscillograph pen 1 mm with an amplifier input signal of 50 millivolts. With proper adjustment, the unit may be used with an oscilloscope or similar equipment. In such operation, the amplifier has a response down no more than 3 db at 5000 cps.

The Universal Amplifier Model RD 5612 00 is designed for use with oscillographs of the Brush "RD" series. The unit may be used with earlier Brush oscillographs if the frequency response of the amplifier is adjusted for use with the penmotors in such oscillographs, as described under "Frequency Compensation of the D.C. Amplifier Section."

SPECIFICATIONS

AS A CARRIER AMPLIFIER

Frequency response	The recording of a constant voltage sine wave modulation of the carrier will be ±1 chart line (mm) of a nominal 10 chart lines (mm) peak to peak, from d.c. to 100 cps when the amplifier is compensated with a Brush oscillograph.
Sensitivity with Brush oscillograph	1 microvolt per chart line (mm).
Maximum voltage gain	1,500,000.
Bridge exciter frequency	2000 cps ±5%. Provision is made to synchronize oscillators of two or more Brush Universal Amplifiers for multiple operation.
Bridge exciter voltage	Maximum 3 volts (120 ohm load).
Measuring range	
Using the Bridge Balance Model RA 5212 00	1.0 to 40,000 microinches per inch per chart line (mm) with one active 50 to 5000 ohm gage (gage factor 1.7 or higher).
Using the LVDT Balance Model RA 5222 00	Determined by type and sensitivity of transducer used. The output of the transducer must be at least 1 microvolt with an input of 50 millivolts at 2000 cps.
Chart multiplier steps	1, 2, 5, 10, 20, 50, 100, 200, 500, and 1000.
Demodulator output	For observation of demodulated signal up to 200 cps (down 2 db at 200 cps).
Noise	Less than ¼ chart line (mm) peak to peak during operation.

AS A MEDIUM GAIN D.C. AMPLIFIER

Frequency response	The recording of a constant voltage sine wave will be ±1 chart line (mm) of a nominal 10 chart lines (mm) peak to peak from d.c. to 100 cps when the amplifier is compensated with a Brush oscillograph. Response ±½db to 1 kc, down no more than 3 db at 5 kc, for use of the d.c. amplifier section with oscilloscopes or for similar applications is obtained by switching off the compensation.

Sensitivity with Brush oscillograph	50 millivolts per chart line (mm). Full scale deflection from chart center ±1 volt.
Voltage gain	Approximately 30.
Measurement range with Brush oscillograph	
Single ended input	0.050 volt to 400 volts.
Balanced input	0.050 volt to 400 volts, side to side. Allowable voltage off ground is 1000 times VOLTS/CHART LINE switch setting (in volts) up to 500 volts off ground.
Amplifier zero line stability	¼ chart line (mm) per hour, when used with a Brush oscillograph and Brush chart paper. (Not affected by power line fluctuations between 105 and 125 volts or between 95 and 115 volts). Total drift over eight hour period not more than ½ chart line (mm).
Input impedance	
Single-ended	5 megohms.
Balanced	10 megohms.
Sensitivity steps	.05, .1, .2, .5, 1, 2, 5, and 10 volts per chart line (mm). Maximum attenuator error 1% with balanced input.
Calibration	Signal derived from internal mercury cell.
Signal expander	A pen positioning control (PEN BIAS) is provided. This control permits balancing out the static component of a complex signal, deflecting the signal zero line as much as 200 lines (ten times full scale deflection) either side of chart center, except when balanced input is used.

GENERAL

Output impedance	Approximately 50 ohms.
Maximum output current	±20 milliamperes into 1500 ohms.
Input power required	105 to 125 volts (or 95 to 115 volts), 50 to 2000 cps, 90 watts (nominal).
Fuse	2 amp, 250 volts, type 3 AG.

Tubes	
Carrier amplifier	1-12AU7, 1-12AX7, 1-12AT7, and 1-6AL5.
D.C. amplifier	1-12AX7, 2-12AT7WA, and 2-5687.
Power supply	1-OA2, 1-6BW4, 1-6080, and 1-5751.
Input terminals	
Front	Binding posts.
Rear	d.c.: 3 pin male AN type (matching connector supplied). bridge: 5 pin female AN type (matching connector supplied). sync: 2 pin male AN type (matching connector supplied).
Output terminals	6 pin female AN type (cables to connect amplifier to Brush "RD" series oscillographs supplied).
Dimensions	
Universal Amplifier	Standard panel: 19″ wide x 5¼″ high x ¼″ thick. Depth: 10¾″ (with connectors, 12½″).
Bridge Balance	Panel: 4½″ wide x 3½″ high x ⅛″ thick. Depth: 2¼″.
LVDT Balance	Panel: 4½″ wide x 3½″ high x ⅛″ thick. Depth: 2¼″.
Net weights	
Universal Amplifier (less balance box)	22 lbs.
Bridge Balance	1 lb., 2 oz.
LVDT Balance	1 lb., 2 oz.
Shipping weights	
Universal Amplifier (less balance box)	28 lbs.
Bridge Balance	2 lbs.
LVDT Balance	2 lbs.

INSTALLING THE INSTRUMENT IN RACK OR PORTABLE CASE

The Universal Amplifier may be installed in a standard 19″ rack or in the Brush Portable Case Model RA 1105 30.

To install the Universal Amplifier in a standard 19″ rack, position the instrument in the rack, secure the front panel to the rack rails with four screws, and connect external cables to the front or rear of the amplifier as described below. Such a permanent installation is desirable when the amplifier is to be used with other rack mounted instruments.

In applications where maximum portability is desired, the Brush Portable Case Model RA 1105 30 is recommended. The case is 20⅛″ wide, 6⅜″ high, and 10⅜″ deep. When the amplifier and Portable Case are purchased together, the amplifier is installed in the case at the factory. Instructions for installing the amplifier are included with the Portable Case when it is purchased separately. The amplifier may be ordered with a 3 conductor power cable for portable applications.

PREPARATION FOR USE

USE WITH OSCILLOGRAPHS

The Brush Universal Amplifier is designed to be used with Brush "RD" series oscillographs. It may be used with Brush "BL" series oscillographs, but frequency response and sensitivity will differ from the values noted under "Specifications".

If the amplifier is used with Brush "BL-200" series oscillographs, circuitry of oscillographs must be inspected to see that resistance between penmotor leads and case exceeds 100 megohms.

If the amplifier is used with a Brush Model BL-206 or Model BL-208 Oscillograph, special conversion information for the oscillograph may be obtained from the Service Department, Brush Instruments, Division of Clevite Corporation, 3405 Perkins Avenue, Cleveland 14, Ohio.

If the amplifier and an oscillograph of the "RD" series are purchased together as a matched recording system, the amplifier is frequency compensated at the factory for operation with that particular oscillograph. If the amplifier and oscillograph are purchased separately, the amplifier must be frequency compensated for use with the oscillograph.

CONNECTING AMPLIFIER TO OSCILLOGRAPH

The output terminals of this amplifier are 30 volts (d.c.) above chassis, and should not be connected to any load in which either terminal is grounded. To connect the amplifier to an oscillograph, proceed as follows:

1. See that the amplifier and oscillograph are disconnected from their power source, and that power switches of the amplifier and oscillograph are in "off" position.

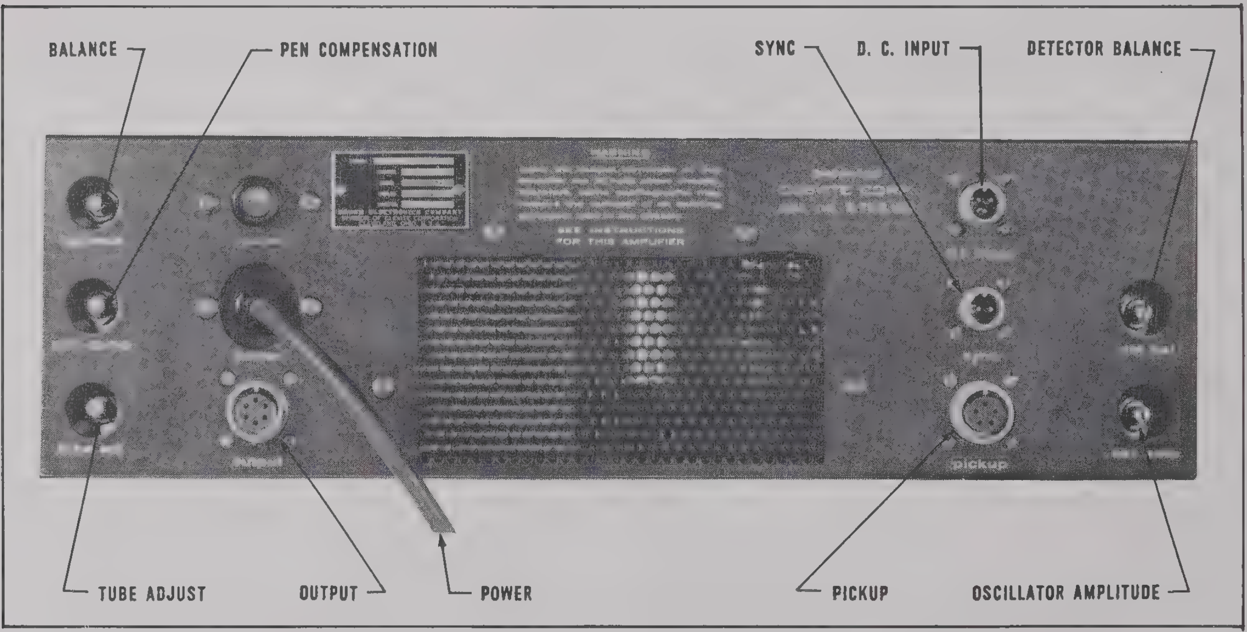


Fig. 1. Rear Panel—Universal Amplifier Model RD 5612 00.

2. Connect the amplifier OUTPUT connector (Fig. 1), on the back of the amplifier, to the oscillograph input connector with the cable supplied.

CONNECTING AMPLIFIER AND OSCILLOGRAPH TO POWER SOURCE

1. Refer to the operating instructions for the oscillograph, and connect the oscillograph to its power source. Test the oscillograph for proper operation, and turn the oscillograph power switch "off".

2. Connect the amplifier POWER cable (Fig. 1) to an appropriate power source. (The amplifier may be operated on power line frequencies from 50 to 2000 cps. Although the amplifier operates normally on power line voltage of 105 to 125 volts, the power transformer connections can be modified for operation at 95 to 115 volts. See "Modification of Power Transformer Connections for Operation at 95 to 115 Volts" in Section V—Maintenance.)

BALANCING AND FREQUENCY COMPENSATION

BALANCING THE D.C. AMPLIFIER SECTION

The d.c. amplifier section should be balanced after connection of the Universal Amplifier and the oscillograph to their power source. To balance the d.c. amplifier section, proceed as follows:

1. Turn the VOLTS/CHART LINE switch (Fig. 2) to "off". Turn the amplifier POWER switch (Fig. 2) to "on" and allow 15 minutes for the amplifier to warm up.

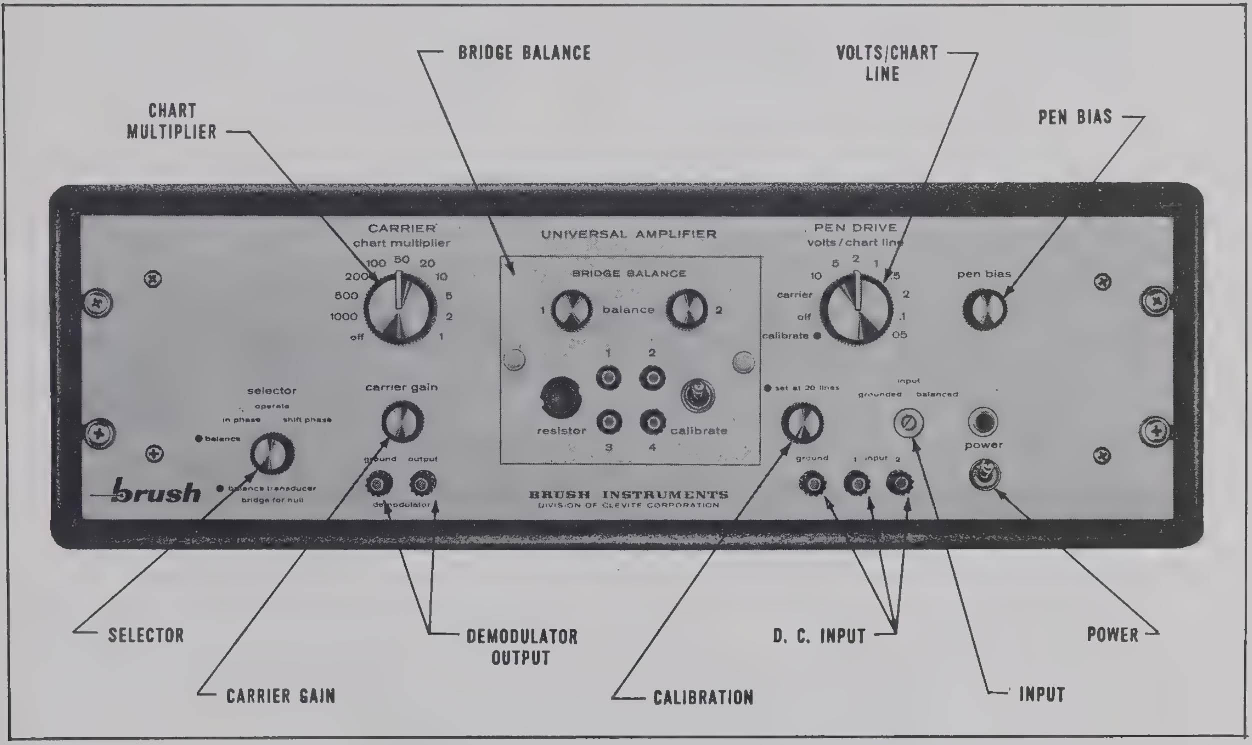


Fig. 2. Universal Amplifier Model RD 5612 00, with Bridge Balance Model RA 5212 00.

2. Turn the oscillograph "on".
3. Set the INPUT switch (Fig. 2) in the "balanced" position.
4. Turn the CALIBRATION control (Fig. 2) full clockwise, then bring the oscillograph pen approximately to chart center by means of the TUBE ADJUST control on the rear panel of the amplifier (Fig. 1).
5. Turn the BALANCE control, on the rear panel of the amplifier (Fig. 1), to its extreme counterclockwise position. Rapidly rotate the CALIBRATION control (Fig. 2), counterclockwise, then clockwise, while turning the BALANCE control slowly clockwise until no pen deflection is noted.
6. Center the pen on the chart by means of the TUBE ADJUST control on the rear panel of the amplifier (Fig. 1), and turn the oscillograph "off".

FREQUENCY COMPENSATION OF THE D.C. AMPLIFIER SECTION

To obtain optimum frequency response of a Brush amplifier-oscillograph combination, the frequency response of the d.c. amplifier section must be adjusted to match the penmotor of the oscillograph. (When an amplifier and an oscillograph are purchased as a matched system, this adjustment is made at the factory. If the instruments are purchased separately, and if frequencies over 30 cps are to be recorded, the frequency compensation procedure must be observed.) When the Universal Amplifier is used with a Brush oscillograph and optimum transient response is desired or flat response to high frequencies is not required, the PEN COMPENSATION control (Fig. 1) may be turned "off" (fully counterclockwise).

To match the d.c. amplifier section to an oscillograph, balance the d.c. amplifier section as described under "Balancing the D.C. Amplifier Section", above, and proceed as follows:

1. Connect an oscillator covering the range from 10 to 100 cps to the INPUT 1 terminal (Fig. 2) and the INPUT 2 terminal (Fig. 2) on the front of the amplifier. If the corresponding D.C. INPUT connector (Fig. 1) on the rear of the amplifier is used, connect the oscillator to pin "A" (ground) and pin "C". To reduce hum pickup, it is recommended that shielded leads be used.
2. Set the INPUT switch (Fig. 2) in the "grounded" position.

   When the INPUT switch (Fig. 2) is in the "grounded" position, the INPUT 1 terminal is shorted to ground, allowing connections to be made at the INPUT 1 and INPUT 2 terminals.
3. Turn the oscillograph "on". Set the VOLTS/CHART LINE switch (Fig. 2) in the "10" position and, with the oscillograph operating at a chart paper speed of 20 or 25 mm/sec, center the oscillograph pen trace on the chart paper by means of the PEN BIAS control (Fig. 2).
4. Set the PEN COMPENSATION control (Fig. 1) in approximately mid-position.
5. At 10 cps, adjust oscillator output level for 10 lines total pen deflection (peak-to-peak). If oscillator output is not sufficient to produce 10 lines of pen deflection, turn the VOLTS/CHART LINE switch to a more sensitive position to produce 10 lines of deflection. It may be necessary to increase or decrease the oscillator output voltage or to change the setting of the CALIBRATION control (Fig. 2) to obtain the desired 10 line deflection.

   The oscillator output voltage is a reference voltage and must be held constant during the frequency compensation procedure. The settings of the oscillator output voltage control, the VOLTS/CHART LINE switch (Fig. 2) and the CALIBRATION control (Fig. 2) must remain unchanged.
6. At 100 cps (with oscillator output voltage the same as in Step 5, above), adjust the PEN COMPENSATION control (Fig. 1) as necessary to obtain a pen deflection of 10 chart lines.
7. Sweep the frequency range from 10 cps to 100 cps (holding oscillator output voltage constant) and check for flatness of response. Adjust the PEN COMPENSATION control (Fig. 1), if necessary, to obtain optimum response from 10 cps to 100 cps. Turn the oscillograph "off".

OPERATION WITH THE BRIDGE BALANCE Model RA 5212 00

INSTALLING AND CONNECTING THE BRIDGE BALANCE

To use the Universal Amplifier with strain gages install the Bridge Balance in the amplifier, as follows:

1. Set the GAGE OHMS switch (Fig. 3) in the highest range including the resistance value of the gage being used.

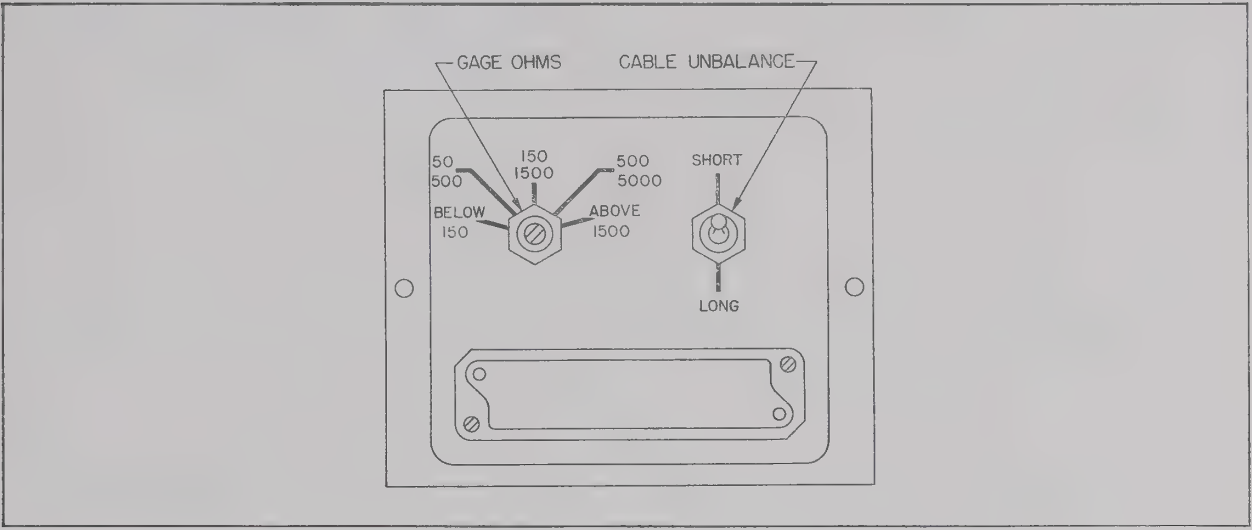


Fig. 3. Rear View—Bridge Balance Model RA 5212 00.

2. Set the CABLE UNBALANCE switch (Fig. 3) in the proper position. For most applications, the switch should be set at "short". However, if the capacitive unbalance to the strain gage bridge in the Bridge Balance is greater than that produced by 10 feet of 40 micro-microfarad per foot microphone cable, set the CABLE UNBALANCE switch in the "long" position.
3. Position the Bridge Balance (Fig. 4) in the amplifier front panel, and secure with two knurled screws.
4. Apply strain gage or gages to the material under test, following the installation instructions supplied by the manufacturer.

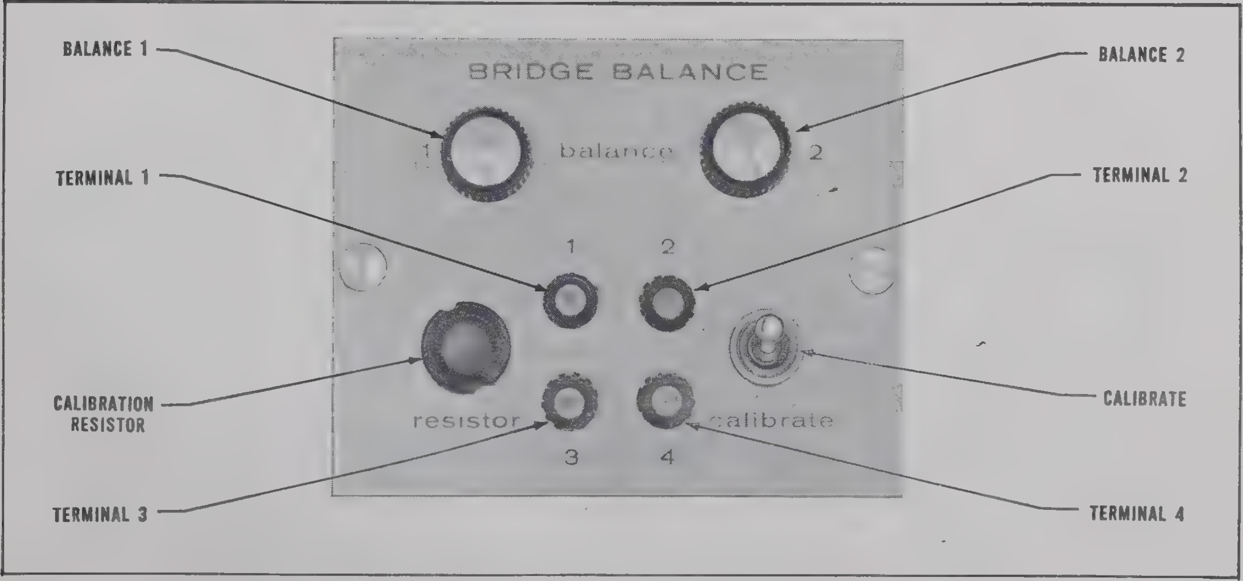


Fig. 4. Bridge Balance Model RA 5212 00.

The Universal Amplifier and the Bridge Balance may be used with many types of strain gages. Strain gage circuits may use one, two, or four active arms of the bridge circuit in the Bridge Balance. If less than four active arms are used, the bridge circuit must be completed by the installation of dummy strain gages or precision wire wound resistors, with the same resistance value (± 1%) as the active gage or gages in use. To facilitate balancing of the bridge circuit, connect dummy gages or resistors to the Bridge Balance with shielded leads, the same length as those connected to the strain gages. Four 120 ohm, wire-wound resistors are included with the Bridge Balance for use with 120 ohm strain gages.

5. Connect the strain gage circuit (or circuits) to the bridge circuit in the Bridge Balance, as described in the following paragraphs. To facilitate comparison of tests made at different times and on different materials, follow a standard procedure in connecting and using strain gages. As a general practice, use the same length leads with all strain gages in the same bridge.

   Strain recordings may be subject to a high degree of error when strain gages are used with high resistance leads. Such error is eliminated through the use of circuits suggested by the strain gage manufacturer.

   If temperature of the material under test remains constant, or if strain measurements are taken over a short period of time, temperature compensation of the strain recording system may not be necessary. However, temperature compensation is necessary in some cases to assure accuracy in strain recordings. The following paragraphs contain more detailed information on temperature compensation in systems using one, two, or four active strain gages.

   Strain gage leads may be connected to the PICKUP connector on the rear panel of the amplifier, rather than to the terminals of the Bridge Balance (Fig. 5).

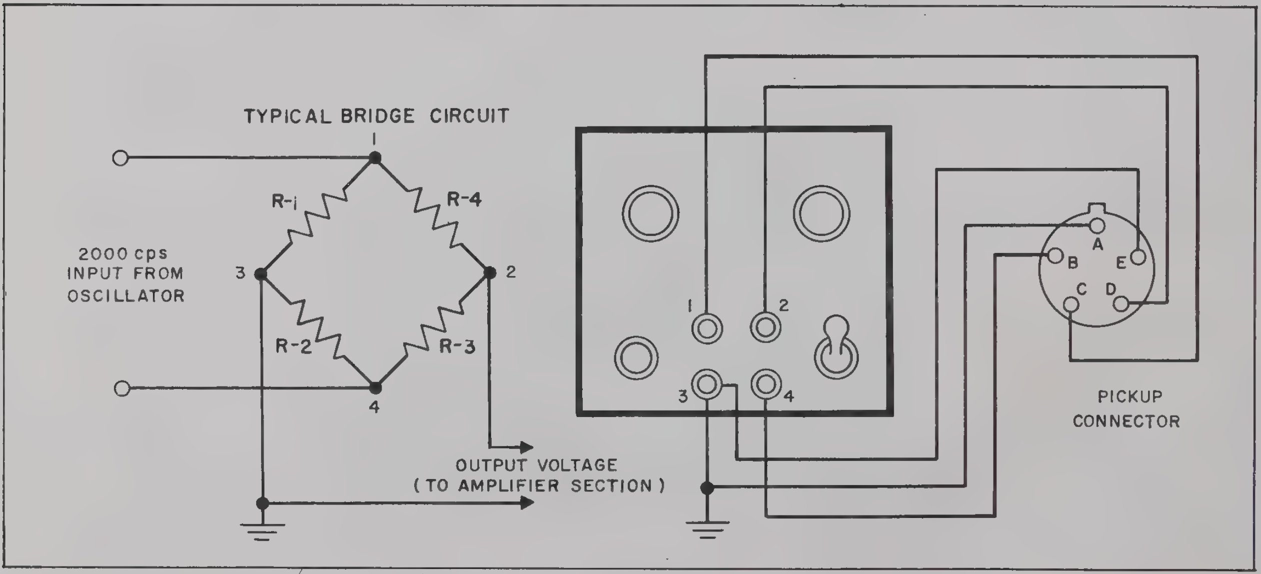


Fig. 5. Connections to the Strain Gage Bridge Circuit in the Bridge Balance.

CALCULATION OF BRIDGE OUTPUT VOLTAGE

The Bridge Balance Model RA 5612 00 is a 4 terminal bridge circuit which is used for strain measurement. A supply voltage is applied at diagonally opposite corners of the bridge, as shown in Figure 5. Output voltage from the circuit is taken from the two other diagonally opposite corners. The output voltage of the bridge circuit may be calculated as follows:

$$V_{R_2} = V\left(\frac{R_2}{R_1 + R_2}\right), \tag{1}$$

$$V_{R_3} = V\left(\frac{R_3}{R_4 + R_3}\right), \tag{2}$$

and

$$V_o = V_{R_2} - V_{R_3}, \tag{3}$$

or

$$V_o = V\left(\frac{R_2}{R_1 + R_2}\right) - V\left(\frac{R_3}{R_4 + R_3}\right), \tag{4}$$

where

V = Supply voltage,

R_1, R_2, etc. = Resistance values of resistors in the bridge circuit,

and

V_o = Bridge output voltage.

The bridge circuit is in balance and zero output voltage results when $R_1 = R_2 = R_3 = R_4$.

If a strain gage of resistance R_g (where $R_g = R_1 = R_2 = R_3 = R_4$) is connected in one arm of the bridge circuit, and if that gage is actuated, the resistance of that gage will be $R_g + \triangle R_g$. Assuming that R_2 is the active gage, then the output voltage from the bridge circuit will be proportional to resistance changes in the one active element, as shown:

$$V_o = V\left(\frac{(R_g + \triangle R_g)}{R_g + (R_g + \triangle R_g)}\right) - V\left(\frac{R_g}{R_g + R_g}\right), \tag{5}$$

so that

$$V_o = V\left(\frac{\triangle R_g}{4R_g + 2(\triangle R_g)}\right). \tag{6}$$

Since

$$2(\triangle R_g) << 4R_g,$$

then

$$V_o = V \cdot \frac{\triangle R_g}{4R_g}. \tag{7}$$

CONNECTING ONE ACTIVE STRAIN GAGE TO THE BRIDGE BALANCE

Without Temperature Compensation

The simplest method of strain measurement employs only one active arm of the strain gage circuit; expansion or contraction of the material under test due to temperature changes is disregarded. To use one strain gage without temperature compensation, connect the gage to the Bridge Balance as shown in Figure 6. Complete the inactive arms of the bridge circuit with precision wire wound resistors or unstressed gages of the same resistance value as the active gage. Under some conditions, variations in the resistance of the active gage or dummy resistors due to small variations in temperature may be large in comparison to the change in resistance of the active gage caused by strain. Since any change in resistance appears in the output of the amplifier and on the chart, the effect of small temperature variations must be checked carefully when measuring small strains.

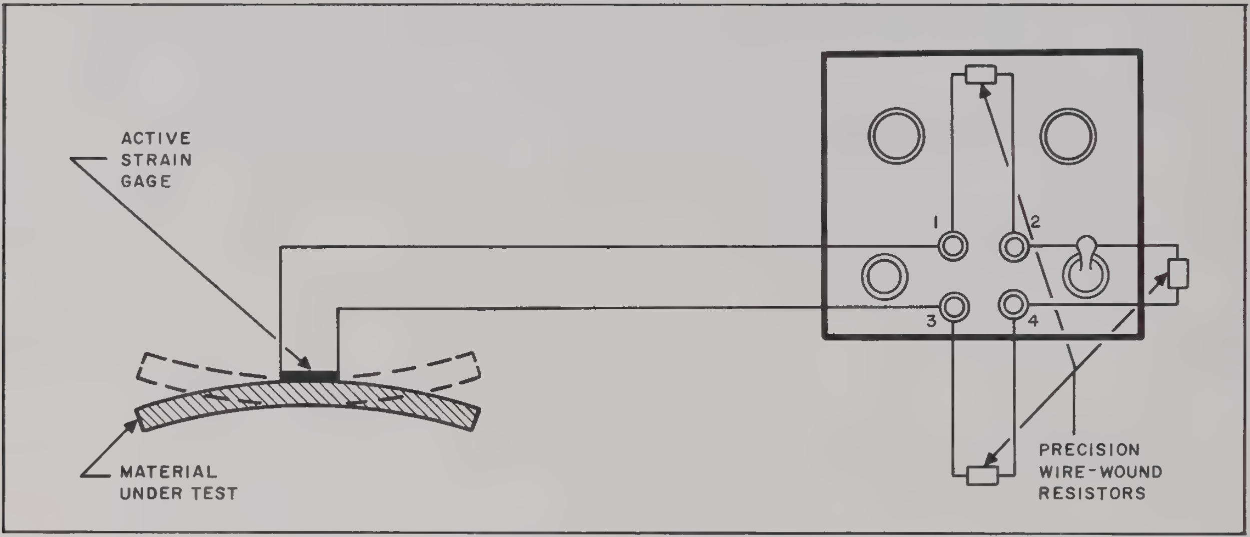


Fig. 6. One Active Strain Gage Connected to the Bridge Balance.

With Temperature Compensation

To compensate for temperature changes in the material being tested, apply a strain gage (of the same resistance value as the active gage) to material of the same composition and in the same temperature zone as the material under test, but not subjected to strain. Connect this inactive gage to the bridge arm adjacent to the active strain gage, as shown in Figure 7.

When one active strain gage is used in a strain recording system, the system is normally calibrated for a sensitivity of 2 microinches per inch of strain per chart millimeter. The internal calibration system in the amplifier permits variation of amplifier gain so that this sensitivity may be obtained for any 50 to 5000 ohm strain gage with a gage factor of 1.7 or higher. If desired, the system may be calibrated for a lower sensitivity.

CONNECTING TWO ACTIVE STRAIN GAGES TO THE BRIDGE BALANCE

A strain recording system using two active strain gages can be calibrated to a sensitivity of 1 microinch per inch of strain per chart millimeter, or twice that of a one-gage system. However, the recorded strain (deflection of the oscillograph pen) depends on connection and mounting of the active strain gages.

Two Active Gages in Adjacent Arms of the Bridge

The recorded strain (output of the bridge circuit) will be twice that for one gage if two active and identical strain gages are connected in adjacent arms and subjected to strains of equal magnitude but of opposite signs. An example of such strain gage application is shown in Figure 8, where two active and identical strain gages are applied to opposite sides of a bending beam or similar piece of material. No temperature compensation is necessary, since changes in resistance value of the gage in compression (resulting from temperature changes in the material under test) are nullified by similar changes in resistance value of the gage in tension.

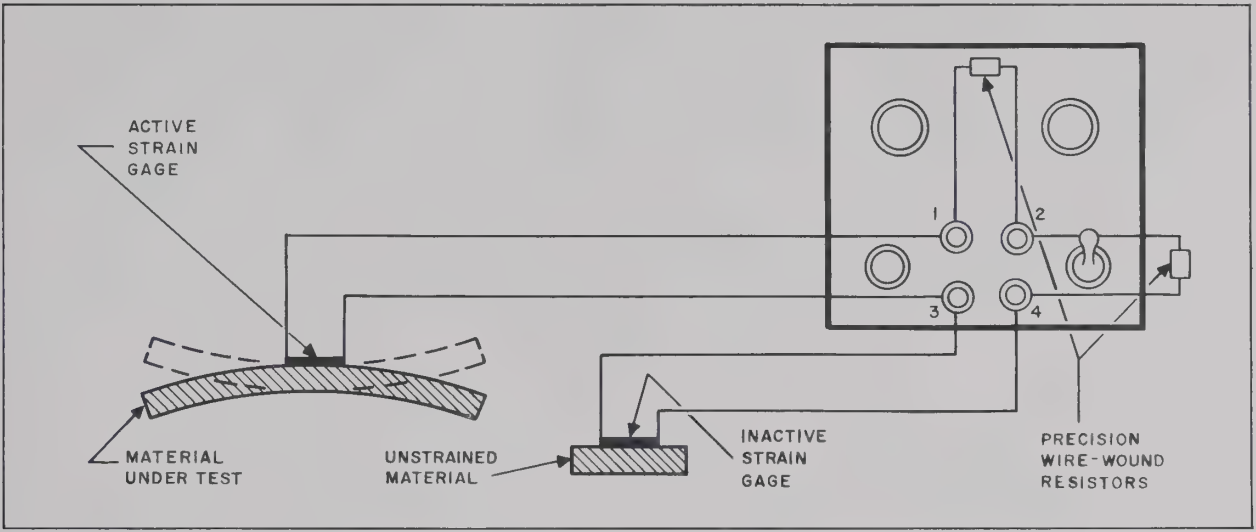


Fig. 7. One Active Strain Gage—Inactive Gage Connected in Circuit for Temperature Compensation.

Where two active strain gages are connected in adjacent arms of the bridge circuit, the output of the bridge is proportional to the algebraic difference between strains in the two gages.

The recorded strain, or output of the bridge circuit, will be zero if two active and identical strain gages are connected in adjacent arms and subjected to strains of equal magnitude and sign.

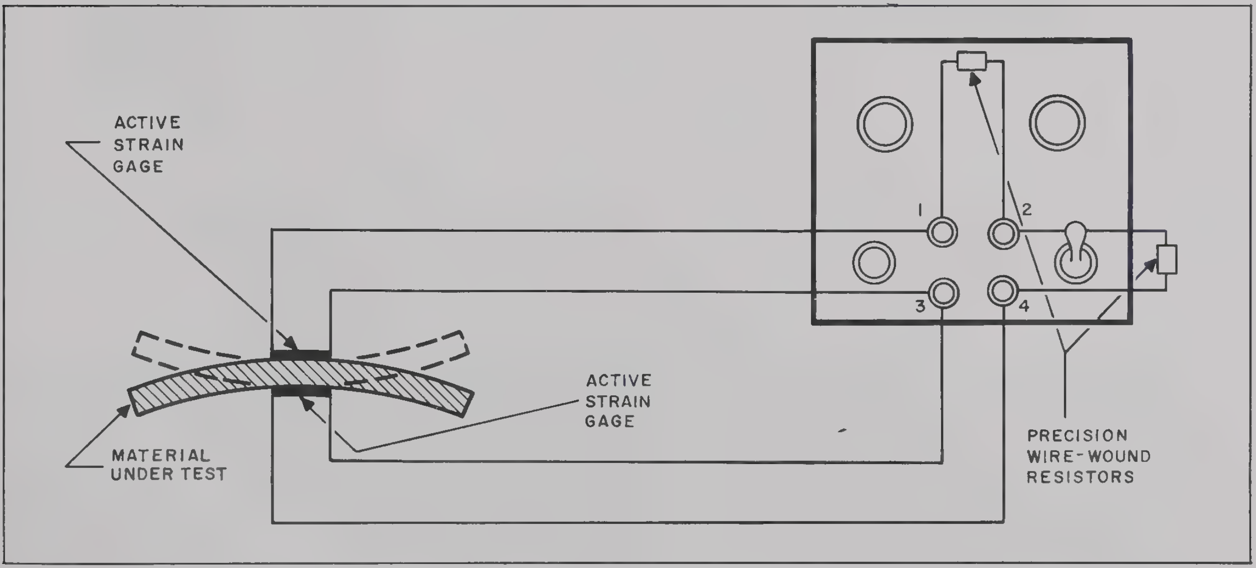


Fig. 8. Two Active Strain Gages—One Measuring Tension, the Other Measuring Compression.

To reverse the direction of pen deflection, transfer all leads from terminal 1 to terminal 4 of the Bridge Balance, and transfer all leads from terminal 4 to terminal 1.

Two Active Gages in Opposite Arms of the Bridge

The recorded strain (output of the bridge circuit) will be twice that for one gage if two active, identical strain gages are connected in opposite arms and subjected to strains of equal magnitude and sign. An example is shown in Figure 9, where two active and identical strain gages are applied side by side on the material under test. If temperature compensation is desired, strain gages of the same gage factor and resistance value as the active gages may be applied to unstressed material of the same composition and in the same temperature environment as the material under test, and connected in the inactive arms of the bridge circuit.

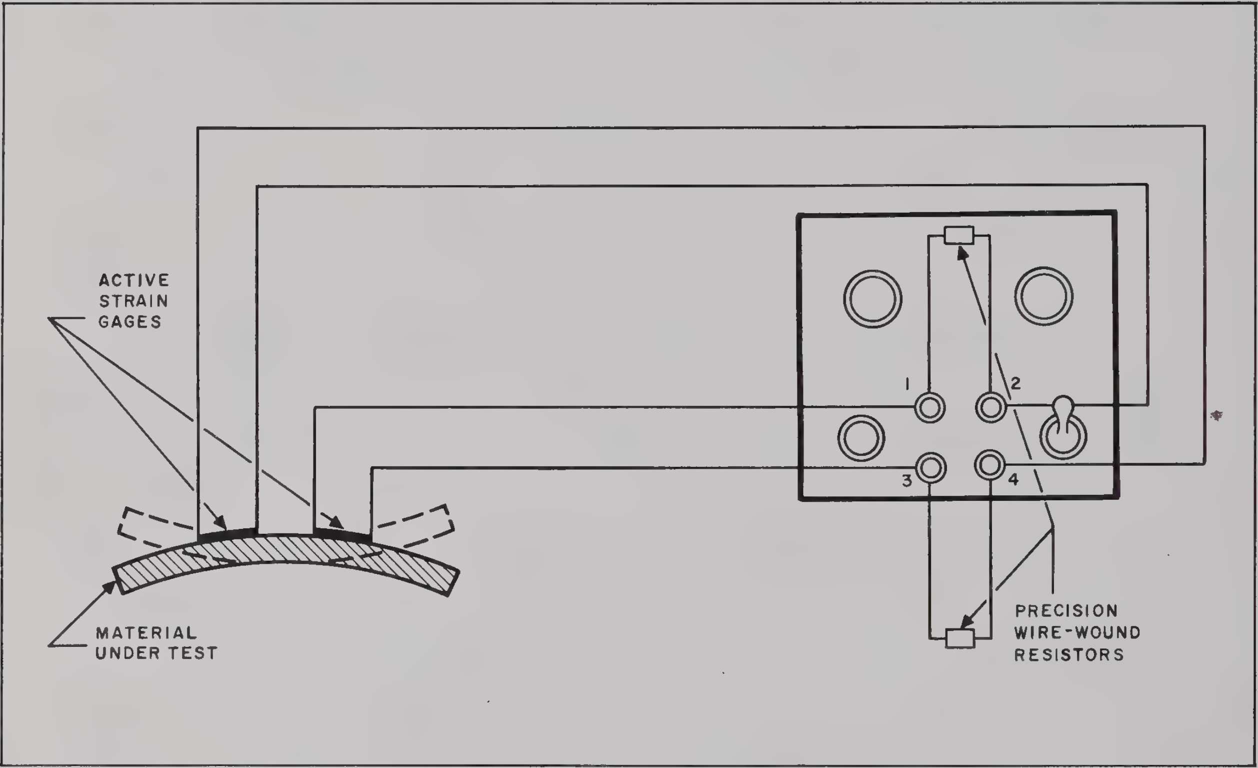


Fig. 9. Two Active Strain Gages Placed Side by Side on Material Under Test.

Where two active strain gages are connected in opposite arms of the bridge circuit, the output of the bridge is proportional to the algebraic sum of strains in the two gages.

The recorded strain, or output of the bridge circuit, will be zero if two active, identical strain gages are connected in opposite arms of the bridge circuit and subjected to strains of equal magnitude and opposite sign.

To reverse the direction of pen deflection, transfer all leads from terminal 1 to terminal 4 of the Bridge Balance, and transfer all leads from terminal 4 to terminal 1.

CONNECTING FOUR ACTIVE STRAIN GAGES TO THE BRIDGE BALANCE

A strain recording system using four active strain gages can be calibrated to a sensitivity of ½ microinch per inch of strain per chart millimeter, or four times that of a one-gage system. However, the recorded strain (deflection of the oscillograph pen) depends on connection and mounting of the active strain gages.

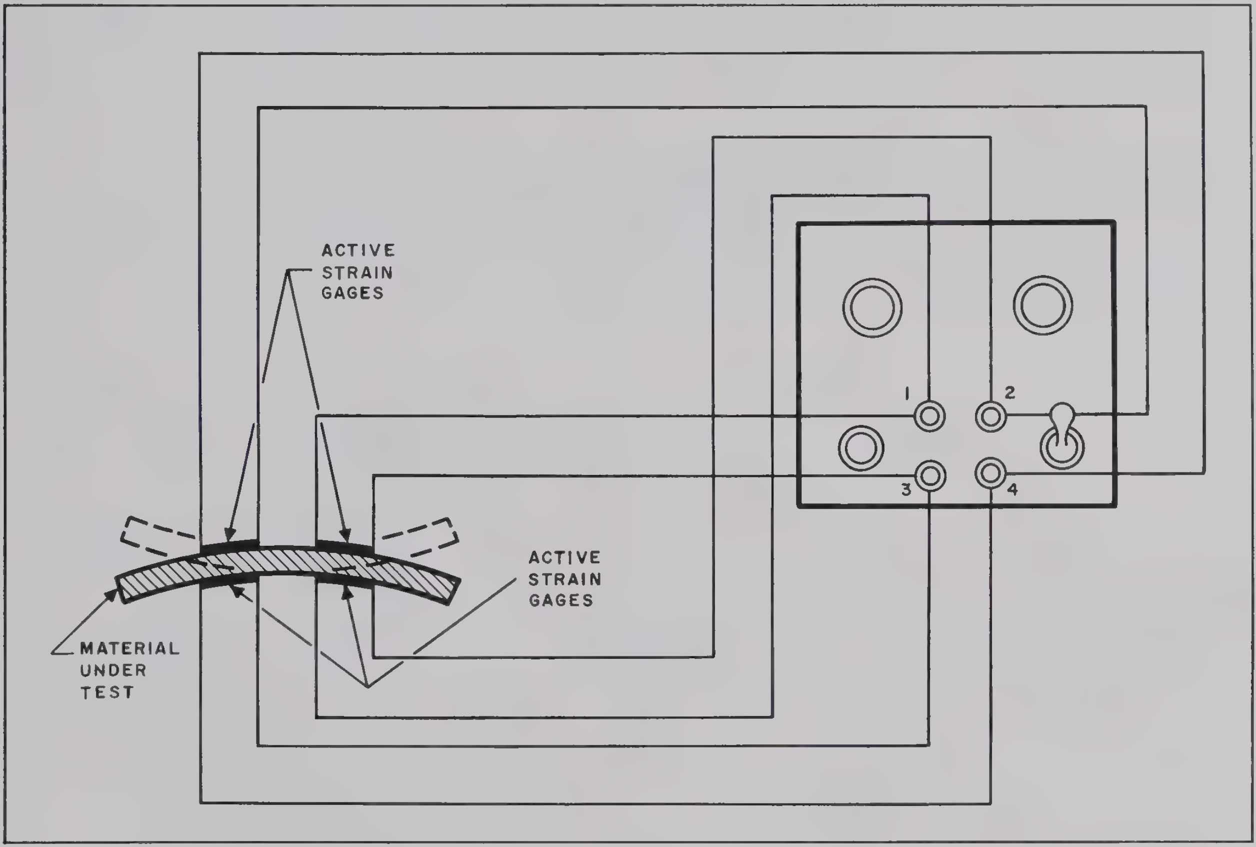


Fig. 10. Four Active Strain Gages—Two Measuring Tension and Two Measuring Compression.

The recorded strain, or output of the bridge circuit, will be four times that for one gage if four active, identical strain gages are connected in the arms of the bridge and subjected to strains of equal magnitude, but of opposite sign for adjacent arms. Figure 10 illustrates such a strain measuring system—at any moment two gages, applied side by side to the material under test, are subjected to tension, while two other gages, applied to the other side of the material, are subjected to compression. Note that the gages in tension and the gages in compression are connected in alternate arms of the bridge circuit. No temperature compensation is necessary, since changes in resistance value of gages in compression (resulting from temperature changes in the material under test) are nullified by similar changes in resistance value of gages in tension.

To reverse the direction of pen deflection, transfer all leads from terminal 1 to terminal 4 of the Bridge Balance, and transfer all leads from terminal 4 to terminal 1.

Output of the four-gage system will be zero if four active, identical gages are subjected to strains of the same magnitude and sign, or if gages in tension are connected to adjacent bridge arms, while gages in compression are also connected to adjacent bridge arms.

CONNECTING A LOAD CELL TO THE BRIDGE BALANCE

The Universal Amplifier and the Bridge Balance may be used with load cells for measuring forces or weighing objects. The load cell should be connected to the Bridge Balance as shown in Figure 11.

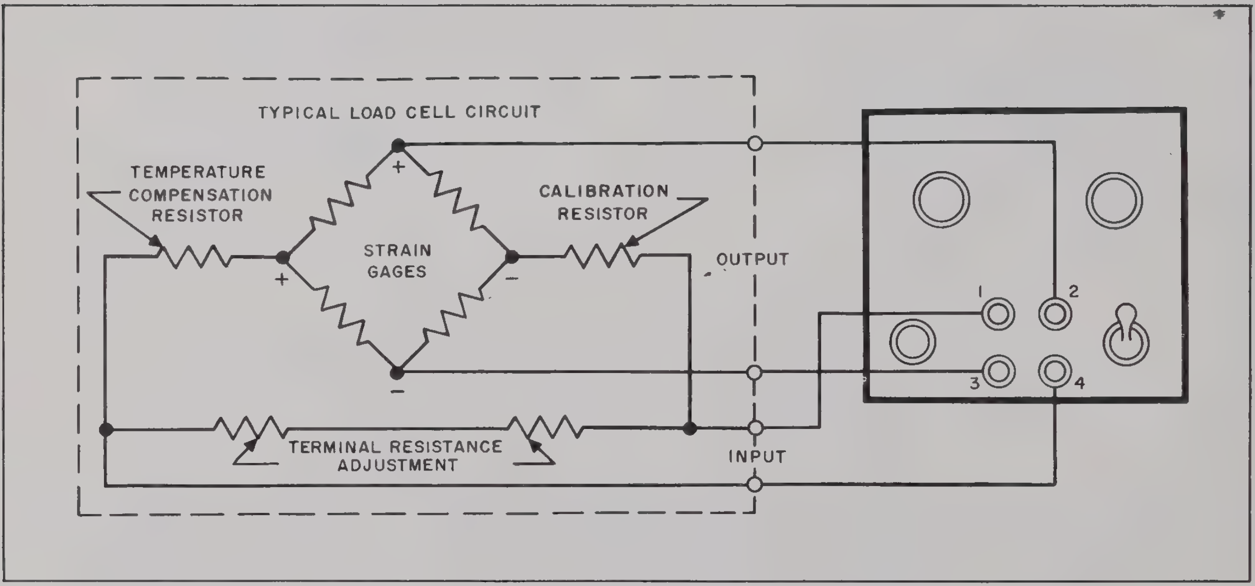

TYPICAL LOAD CELL CIRCUIT
TEMPERATURE COMPENSATION RESISTOR
STRAIN GAGES
CALIBRATION RESISTOR
OUTPUT
TERMINAL RESISTANCE ADJUSTMENT
INPUT
+
+
–
–
1
2
3
4

Fig. 11. Typical Load Cell Connected to the Bridge Balance.

Do not connect more than one load cell to each Universal Amplifier in a system.

BALANCING THE UNIVERSAL AMPLIFIER FOR USE WITH THE BRIDGE BALANCE

For satisfactory recording, the Universal Amplifier and strain gage circuit must be balanced and calibrated. The balancing and calibration procedures need not be repeated so long as the same strain gages, in the same positions, are used in a particular strain gage circuit with the Bridge Balance. If information concerning the static component of a complex signal is known or may be disregarded, the balancing procedures described below may be followed with full static load applied to the bridge circuit. In such a case, the balancing procedures serve to cancel the *static* portion of the signal, permitting *only* the *dynamic* portion of the signal to be recorded.

If the static component is not known but is to be considered, balance the system in the "no load" condition, then apply full static load. Note pen deflection caused by application of the static load. Balance the system once more in the usual manner, moving the dynamic recording to chart center. For convenient study of the dynamic recording, increase the sensitivity of the amplifier by turning the CHART MULTIPLIER switch (Fig. 2) to "500", "200", etc.

After following the procedures described under "Balancing and Frequency Compensation," above, see that the Bridge Balance is installed and connected to the strain gage circuit. With the strain gage bridge circuit complete and with no dynamic signal being transmitted from the strain gage circuit to the amplifier, balance the system, proceeding as follows:

1. Turn the VOLTS/CHART LINE switch (Fig. 2) to the "carrier" position. Set the INPUT switch (Fig. 2) in the "grounded" position. Turn the CHART MULTIPLIER switch (Fig. 2) to the "off" position, and set the SELECTOR switch (Fig. 2) in the "balance" position.

2. Turn the amplifier POWER switch (Fig. 2) to "on" position, and allow 15 minutes for the amplifier to warm up.

3. Turn the oscillograph "on" and, by means of the PEN BIAS control (Fig. 2), move the pen to chart center. *This establishes the center line of the chart paper as the zero reference line for the balancing procedure only.*

4. Turn the CARRIER GAIN control (Fig. 2) to its full counterclockwise (low gain) position.

5. Set the CHART MULTIPLIER switch (Fig. 2) in the "1000" position and, by turning the CARRIER GAIN control (Fig. 2) in a clockwise direction, move the oscillograph pen an appreciable distance (10 to 15 lines) from chart center.

6. Adjust the BALANCE 1 and BALANCE 2 controls on the Bridge Balance (Fig. 4) alternately until the oscillograph pen is, as nearly as possible, on the center line of the chart paper.

If the oscillograph pen cannot be brought to chart center by the above procedure, refer to "Resistive Unbalance" and "Reactive Unbalance" below.

7. Set the CHART MULTIPLIER switch (Fig. 2) in a more sensitive position ("500", "200", etc.) and, by turning the CARRIER GAIN control (Fig. 2) in a clockwise direction, move the pen from chart center. Alternately adjust the BALANCE 1 and BALANCE 2 controls (Fig. 4) to center the pen. Repeat this procedure until the CHART MULTIPLIER switch is in the "1" position and the CARRIER GAIN control is in its extreme clockwise (full gain) position.

At this time it is necessary only to bring the pen to within 15 or 20 lines of chart center. Precise balance is not required, since the accuracy and linearity of the Universal Amplifier are not affected by small unbalances.

8. Turn the SELECTOR switch (Fig. 2) to the "in phase" position. Turn the CHART MULTIPLIER switch (Fig. 2) "off", and re-adjust the pen to chart center by means of the PEN BIAS control (Fig. 2).
9. Set the CHART MULTIPLIER switch (Fig. 2) in the desired position and adjust the pen to chart center by means of the BALANCE 1 control (Fig. 4) on the Bridge Balance, to eliminate any unbalance remaining after completion of step 7, above.

Resistive Unbalance

If it is not possible to move the oscillograph pen through a minimum or null position near the center line of the chart paper by means of the BALANCE 1 control (Fig. 4), remove the Bridge Balance from the amplifier and set the GAGE OHMS switch (Fig. 3) in the next lower resistance position. Install the Bridge Balance in the amplifier and continue with the balancing procedure.

Reactive Unbalance

If it is not possible to move the oscillograph pen through a minimum or null position near the center line of the chart paper by means of the BALANCE 2 control, a reactive unbalance condition exists. This condition can be corrected by removing the Bridge Balance from the amplifier, setting the CABLE UNBALANCE switch (Fig. 3) in the "long" position, and replacing the Bridge Balance in the amplifier. After installing the Bridge Balance continue with the balancing procedure. The unbalance condition results from the use of leads of unequal length.

If a reactive unbalance condition still exists when the CABLE UNBALANCE switch is in the "long" position, replace the Bridge Balance and connect padding capacitors across the arm adjacent to the arm with the longest lead. Value of the padding capacitors should be approximately equal to the difference in length (in feet) of strain gage lead cables multiplied by the capacitance per foot of lead cable used.

CALIBRATION OF THE UNIVERSAL AMPLIFIER FOR USE WITH THE BRIDGE BALANCE

The strain recording system may be calibrated so that the oscillograph chart is read directly in microinches per inch of strain per chart line (mm). Nomographs are provided to simplify calibration of systems with one, two, or four active gages once the gage resistance and gage factor of the active gages are known. When the nomographs and the accompanying procedure are used, the system is calibrated to a sensitivity of 1 microinch per inch per chart line (mm), when the Chart Multiplier switch is in the "1" position; 2 microinches per inch per chart line (mm) when the Chart Multiplier switch is in the "2" position; 5 microinches per inch per chart line (mm) when the Chart Multiplier switch is in the "5" position, etc.

When the calibrate switch is depressed, a calibration resistor is connected across terminals 1 and 3 of the Bridge Balance in parallel with the gage connected across these terminals. The effect of this added resistor is to unbalance the bridge, so that an output voltage is produced which simulates the voltage produced by strain on an active gage.

The nomographs are derived from: $\left(\frac{\Delta L}{L}\right)_c = \frac{R}{F_m N R_c}$,

where $\left(\frac{\Delta L}{L}\right)_c$ = Strain simulated by calibration procedure,

R = resistance value of each active gage,

F_m = gage factor for each active gage $\left(\frac{\Delta R}{R} \Big/ \frac{\Delta L}{L}\right)$,

N = number of active gages,

R_c = resistance value of calibration resistor.

(A 390 K calibration resistor is supplied as standard in the RA 5212 00 Bridge Balance box and is the value used for R_c in deriving the nomographs.)

Select the nomograph designed for the number of active gages used. Place a straight edge across the nomograph intersecting the "Gage Factor" and "Gage Resistance" scales at the appropriate points. The straight edge will intersect the center scale indicating the Chart Multiplier switch setting and number of chart lines (mm) of pen deflection. For example, if two active strain gages are used with a gage factor of 2.05 and a restance value of 120 ohms, the nomograph indicates a Chart Multiplier switch setting of 5 and a pen deflection of 15 chart lines (mm).

After the Chart Multiplier switch setting and required pen deflection have been determined, calibrate the strain recording system in the following manner:

1. Set the Chart Multiplier switch in the position indicated by the nomograph.
2. Adjust the Carrier Gain Control for pen deflection equal to the number of chart lines (mm) indicated on the nomograph while depressing and releasing the Calibrate switch.

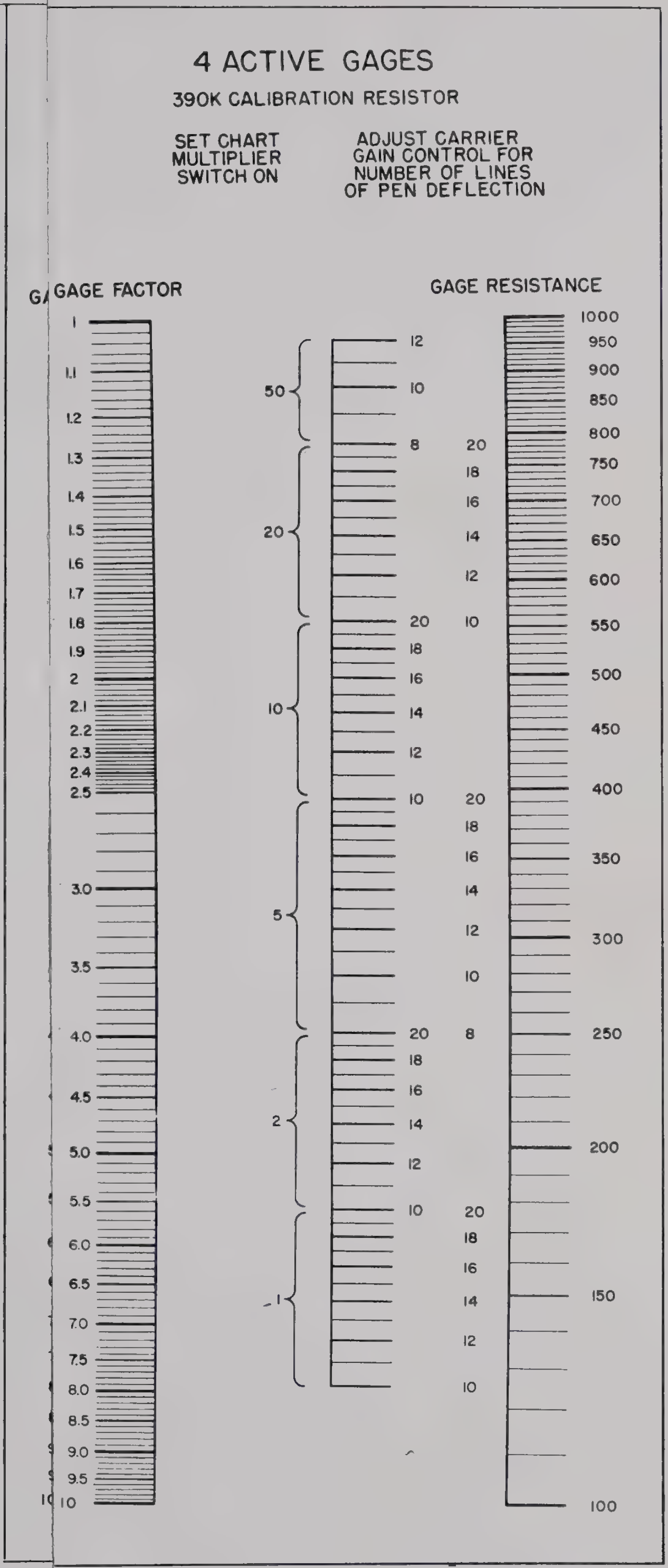
If the Chart Multiplier switch is turned to the "1" position, after calibration, each chart line (mm) of pen deflection represents a strain of 1 microinch per inch; when the Chart Multiplier switch is turned to the "5" position, each chart line (mm) of pen deflection represents a strain of 5 microinches per inch, etc. Thus, to determine the amount of strain in microinches per inch when actual strain is being recorded, multiply the number of lines of pen deflection by the Chart Multiplier switch setting. The Chart Multiplier switch setting should be noted on the chart when a recording is being made to permit analysis of the chart at some later date.

USE OF THE NOMOGRAPHS

1. Select the nomograph appropriate for the number of active gages used.
2. Place a straight edge across the nomograph, intersecting the "Gage Factor" and "Gage Resistance" scales at appropriate points. Intersection of the straight edge with the center scale indicates the CHART MULTIPLIER switch setting and number of chart lines (mm) of pen deflection for calibration.
3. To calibrate system, set the CHART MULTIPLIER switch as indicated in 2, above, and adjust CARRIER GAIN control to obtain a pen deflection equal to number of chart lines (mm) indicated in 2, above, while depressing and releasing CALIBRATE switch.

   After calibration, with CHART MULTIPLIER switch in "1" position, each chart line (mm) of pen deflection represents a strain of 1 microinch per inch; with the CHART MULTIPLIER switch in "5" position, each chart line (mm) of pen deflection represents a strain of 5 microinches per inch, etc.

   Thus, to determine the amount of strain in microinches per inch, multiply the number of lines of pen deflection by CHART MULTIPLIER switch setting.



LTIPLIER SWITCH IS IN THE "I" POSITION.

CALIBRATION OF THE UNIVERSAL AMPLIFIER FOR USE WITH THE BRIDGE BALANCE

The strain recording system may be calibrated so that the oscillograph chart is read directly in microinches per inch of strain per chart line (mm). Nomographs are provided to simplify calibration of systems with one, two, or four active gages once the gage resistance and gage factor of the active gages are known. When the nomographs and the accompanying procedure are used, the system is calibrated to a sensitivity of 1 microinch per inch per chart line (mm), when the Chart Multiplier switch is in the "1" position; 2 microinches per inch per chart line (mm) when the Chart Multiplier switch is in the "2" position; 5 microinches per inch per chart line (mm) when the Chart Multiplier switch is in the "5" position, etc.

When the calibrate switch is depressed, a calibration resistor is connected across terminals 1 and 3 of the Bridge Balance in parallel with the gage connected across these terminals. The effect of this added resistor is to unbalance the bridge, so that an output voltage is produced which simulates the voltage produced by strain on an active gage.

The nomographs are derived from: $\left(\frac{\Delta L}{L}\right)_c = \frac{R}{F_m N R_c}$,

where $\left(\frac{\Delta L}{L}\right)_c$ = Strain simulated by calibration procedure,

R = resistance value of each active gage,

F_m = gage factor for each active gage $\left(\frac{\Delta R}{R} \Big/ \frac{\Delta L}{L}\right)$,

N = number of active gages,

R_c = resistance value of calibration resistor.

(A 390 K calibration resistor is supplied as standard in the RA 5212 00 Bridge Balance box and is the value used for R_c in deriving the nomographs.)

Select the nomograph designed for the number of active gages used. Place a straight edge across the nomograph intersecting the "Gage Factor" and "Gage Resistance" scales at the appropriate points. The straight edge will intersect the center scale indicating the Chart Multiplier switch setting and number of chart lines (mm) of pen deflection. For example, if two active strain gages are used with a gage factor of 2.05 and a restance value of 120 ohms, the nomograph indicates a Chart Multiplier switch setting of 5 and a pen deflection of 15 chart lines (mm).

After the Chart Multiplier switch setting and required pen deflection have been determined, calibrate the strain recording system in the following manner:

1. Set the Chart Multiplier switch in the position indicated by the nomograph.
2. Adjust the Carrier Gain Control for pen deflection equal to the number of chart lines (mm) indicated on the nomograph while depressing and releasing the Calibrate switch.

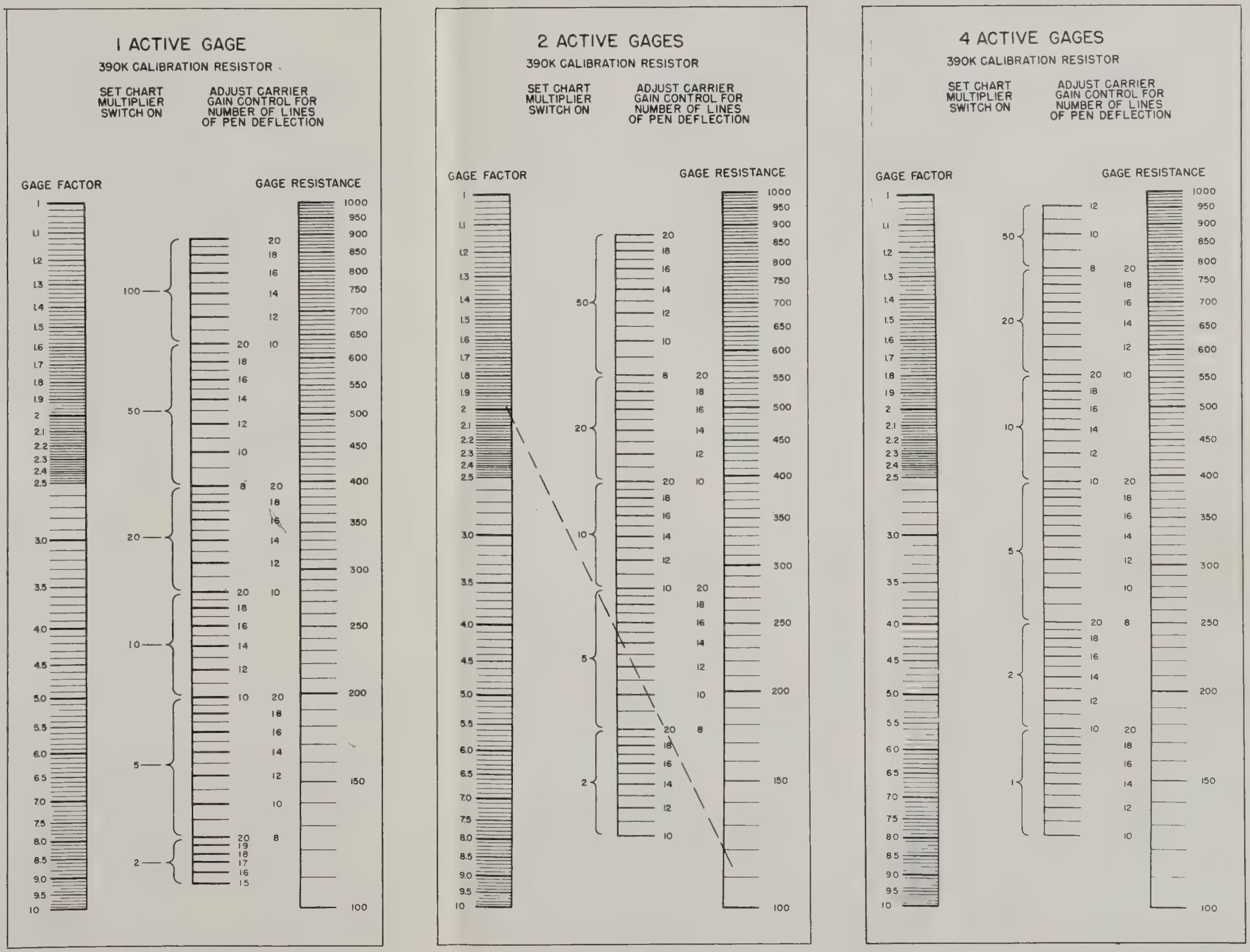
If the Chart Multiplier switch is turned to the "1" position, after calibration, each chart line (mm) of pen deflection represents a strain of 1 microinch per inch; when the Chart Multiplier switch is turned to the "5" position, each chart line (mm) of pen deflection represents a strain of 5 microinches per inch, etc. Thus, to determine the amount of strain in microinches per inch when actual strain is being recorded, multiply the number of lines of pen deflection by the Chart Multiplier switch setting. The Chart Multiplier switch setting should be noted on the chart when a recording is being made to permit analysis of the chart at some later date.

USE OF THE NOMOGRAPHS

1. Select the nomograph appropriate for the number of active gages used.
2. Place a straight edge across the nomograph, intersecting the "Gage Factor" and "Gage Resistance" scales at appropriate points. Intersection of the straight edge with the center scale indicates the CHART MULTIPLIER switch setting and number of chart lines (mm) of pen deflection for calibration.
3. To calibrate system, set the CHART MULTIPLIER switch as indicated in 2, above, and adjust CARRIER GAIN control to obtain a pen deflection equal to number of chart lines (mm) indicated in 2, above, while depressing and releasing CALIBRATE switch.

   After calibration, with CHART MULTIPLIER switch in "1" position, each chart line (mm) of pen deflection represents a strain of 1 microinch per inch; with the CHART MULTIPLIER switch in "5" position, each chart line (mm) of pen deflection represents a strain of 5 microinches per inch, etc.

   Thus, to determine the amount of strain in microinches per inch, multiply the number of lines of pen deflection by CHART MULTIPLIER switch setting.



NOTE: THE NOMOGRAPHS ARE DERIVED FOR A SENSITIVITY OF ONE MICRO INCH/INCH/CHART LINE (MM) WHEN THE CHART MULTIPLIER SWITCH IS IN THE "1" POSITION.

Fig. 12. Nomographs.

Use With Load Cells

Do not attempt to calibrate a load cell circuit with the 390K CALIBRATION RESISTOR in the Bridge Balance (Fig. 4). If calibration of the system with an internal resistor is desirable, contact the load cell manufacturer for appropriate resistor value. Where possible, calibrate the circuit with a known load, as follows:

1. Set the VOLTS/CHART LINE switch (Fig. 2) in the "carrier" position, and set the SELECTOR switch (Fig. 2) in the "in phase" position.
   Apply a known load to the load cell. Set the CHART MULTIPLIER switch (Fig. 2) and the CARRIER GAIN control (Fig. 2) as necessary to produce a suitable deflection (10 or 20 lines, for example). Remove load from the load cell.
2. Without changing the settings of the CHART MULTIPLIER switch (Fig. 2) and the CARRIER GAIN control (Fig. 2), depress the CALIBRATE switch on the Bridge Balance (Fig. 4) and note pen deflection. If the CHART MULTIPLIER switch or CARRIER GAIN control should be moved by accident between readings, depress the CALIBRATE switch and reset the controls to produce the deflection noted above.

NORMAL OPERATION OF THE UNIVERSAL AMPLIFIER WITH THE BRIDGE BALANCE

1. Adjust the oscillograph pen to any desired zero reference position on the chart with the PEN BIAS control (Fig. 2). Do not use the PEN BIAS control to establish a pen zero position *off* the chart paper.
2. With the strain gage circuit complete, and with the system balanced and calibrated as described above, set the VOLTS/CHART LINE switch (Fig. 2) in the "carrier" position, and set the INPUT switch (Fig. 2) in the "grounded" position.
3. Apply load to the strain gage circuit and turn the CHART MULTIPLIER switch (Fig. 2) to "1000", "500", etc., to reach the desired sensitivity. For interpretation of the oscillograph record, refer to "Calibration of the Universal Amplifier for Use with the Bridge Balance Model RA 5212 00", above.

If two or more Universal Amplifiers are being operated simultaneously to record related information, oscillator circuits in the amplifiers should be synchronized. To do this, interconnect the amplifiers through the SYNC connectors (Fig. 1) by means of suitable wiring and the cable connectors supplied with the amplifiers. Pins "A" and "B" on each matching sync input connector (female) should be connected in parallel with pins "A" and "B", respectively, on every other matching sync input connector in the system of amplifiers. When oscillator circuits are synchronized, all interconnected amplifiers must be turned on for operation of *any* of the amplifiers.

OFF-CENTER ZERO OPERATION OF THE UNIVERSAL AMPLIFIER WHEN USED WITH THE BRIDGE BALANCE

It is sometimes desirable, when the Universal Amplifier is being used in strain measurement, to expand the dynamic component of a complex signal for more detailed study. It is possible, by adjusting the zero position of the signal off the chart paper, to cancel the static component and magnify the amplitude of the recording representing the dynamic component. This cancellation is accomplished by means of the BALANCE 1 control on the Bridge Balance (Fig. 4) and the CHART MULTIPLIER switch (Fig. 2). With the amplifier balanced, as described under "Balancing the Universal Amplifier for Use with the Bridge Balance Model RA 5212 00," above, proceed with off-center zero operation as follows:

1. Set the SELECTOR switch (Fig. 2) in the "in phase" position, and turn the CHART MULTIPLIER switch (Fig. 2) to the "off" position.
2. Apply the complex load to the bridge circuit, and turn the CHART MULTIPLIER switch (Fig. 2) to "1000", "500", etc., until the oscillograph pen is off the edge of the chart paper; turn the CHART MULTIPLIER switch back to its last previous setting.
3. By means of the BALANCE 1 control (Fig. 4), adjust the pen trace until the pen records equal amplitudes of the dynamic signal component either side of chart center.
4. Turn the CHART MULTIPLIER switch (Fig. 2) to a lower, or more sensitive position ("200", "100", etc.), to increase the amplitude of the dynamic signal recording.
5. If necessary, return the pen to chart center by means of the BALANCE 1 control (Fig. 4).

The gain and linearity of the amplifier are not affected if the static component cancellation on any CHART MULTIPLIER switch setting is within the range of the BALANCE 1 and BALANCE 2 controls on the Bridge Balance (Fig. 4).

OPERATION WITH THE LVDT BALANCE Model RA 5222 00

INSTALLING AND CONNECTING THE LVDT BALANCE

To use the Universal Amplifier with LVDT (linear variable differential transformer) transducers, install the LVDT Balance in the amplifier (Fig. 13), as follows:

1. Set the LVDT RANGE switch (Fig. 14) in the "low" position. This is the more sensitive position and the position more often used. If the amplitude of the signal is too great to be recorded by the oscillograph, the LVDT RANGE switch can be set in the "high" position. This introduces a capacitor in the circuit to reduce sensitivity of the amplifier.

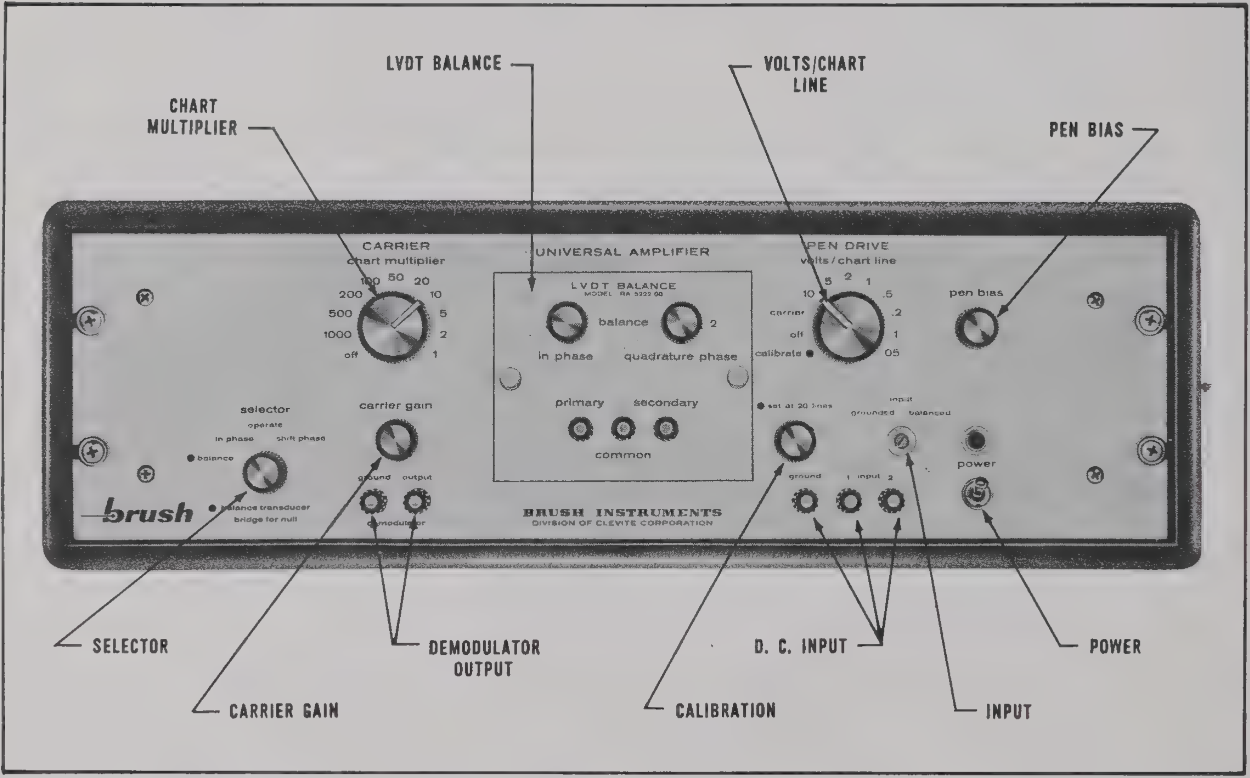


Fig. 13. Universal Amplifier Model RD 5612 00 with LVDT Balance Model RA 5222 00.

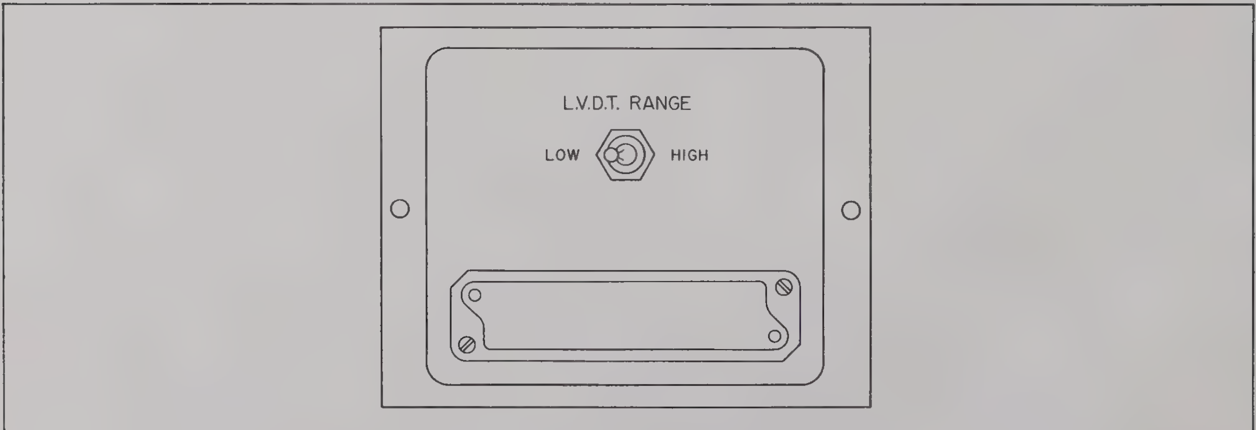


Fig. 14. Rear View—LVDT Balance Model RA 5222 00.

2. Position the LVDT Balance (Fig. 15) in the amplifier front panel, and secure with two knurled screws.
3. Install the transducer to be used with the Universal Amplifier, following the installation instructions supplied by the manufacturer.

Many different types of LVDT transducers are in common use. To facilitate comparison of test results obtained with different transducers, follow a standard procedure in the installation and application of transducers.

4. Connect one lead from the primary winding in the transducer to the PRIMARY terminal on the face of the LVDT Balance (Fig. 15).
5. Connect one lead from the secondary winding in the transducer to the SECONDARY terminal on the face of the LVDT Balance (Fig. 15).
6. Connect one lead from the primary winding and one lead from the secondary winding of the transducer to the COMMON terminal on the face of the LVDT Balance (Fig. 15).

Transducer leads may be connected to the PICKUP connector on the rear panel of the amplifier, rather than to the terminals of the LVDT Balance (Fig. 16).

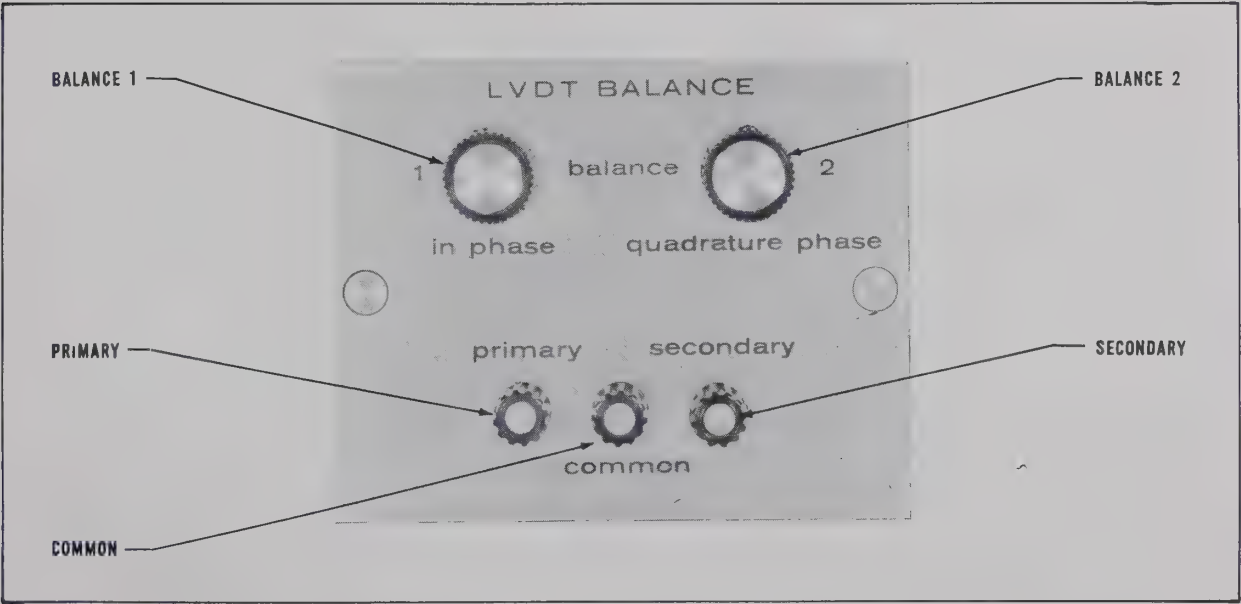


Fig. 15. LVDT Balance Model RA 5222 00.

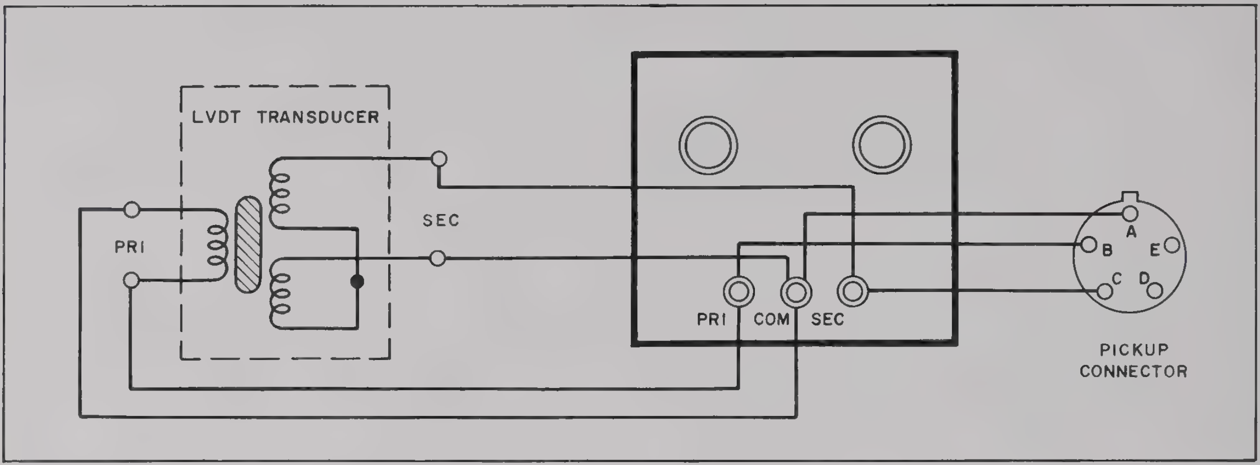


Fig. 16. Typical LVDT Transducer Connected to the LVDT Balance.

BALANCING THE UNIVERSAL AMPLIFIER FOR USE WITH THE LVDT BALANCE

For satisfactory recording, the Universal Amplifier and transducer circuit must be balanced and calibrated. The balancing and calibration procedures need not be repeated so long as a particular transducer is used with the LVDT Balance. If information concerning the static component of a complex signal is known or may be disregarded, the procedures described below may be followed with full static load applied to the transducer. In this case, the balancing procedures serve to cancel the *static* portion of the signal, permitting *only* the *dynamic* portion of the signal to be recorded. It is possible, however, for the static load to exceed the range of the BALANCE 1 and BALANCE 2 controls (Fig. 15). Such a condition will prevent balancing of the system with static load applied to the transducer. Apply full static load to the material under test and install the transducer in the "no load" or "zero output" condition; the transducer will then be actuated only by the dynamic signal.

If the static component is not known, but is to be considered, balance the system in the "no load" condition, then apply full static load. Note the pen deflection caused by application of the static load. Balance the system once more in the usual manner, moving the dynamic recording to chart center. For convenient study of the dynamic recording, increase the sensitivity of the amplifier by turning the CHART MULTIPLIER switch (Fig. 13) to "500", "200", etc. In this type operation, the transducer must be of the correct linear range to accommodate the static and dynamic signals.

After following the procedures described under "Balancing and Frequency Compensation", above, see that the LVDT Balance is installed and connected to the transducer. With no dynamic load applied to the transducer, balance the system, proceeding as follows:

1. Turn the VOLTS/CHART LINE switch (Fig. 13) to the "carrier" position. Set the INPUT switch (Fig. 13) in the "grounded" position. Turn the CHART MULTIPLIER switch (Fig. 13) to the "off" position, and set the SELECTOR switch (Fig. 13) in the "balance" position.
2. Turn the amplifier POWER switch (Fig. 13) to "on" position, and allow 15 minutes for the amplifier to warm up.

3. Turn the oscillograph "on" and, by means of the PEN BIAS control (Fig. 13), move the pen to chart center. *This establishes the center line of the chart paper as the zero reference line for the balancing procedure only.*
4. Turn the CARRIER GAIN control (Fig. 13) to full counterclockwise (low gain) position.
5. Set the CHART MULTIPLIER switch (Fig. 13) in the "1000" position and, by turning the CARRIER GAIN control (Fig. 13) in a clockwise direction, move the oscillograph pen an appreciable distance (10 to 15 lines) from chart center.
6. Adjust the BALANCE 1 and BALANCE 2 controls on the LVDT Balance (Fig. 15) alternately until the oscillograph pen is, as nearly as possible, on the chart center line.
7. Set the CHART MULTIPLIER switch (Fig. 13) in a more sensitive position ("500", "200", etc.) and, by turning the CARRIER GAIN control (Fig. 13) in a clockwise direction, move the pen from chart center. Alternately adjust the BALANCE 1 and BALANCE 2 controls (Fig. 15) to center the pen. Repeat this procedure until the CHART MULTIPLIER switch is in the "1" position and the CARRIER GAIN control is in its extreme clockwise (full gain) position.

At this time it is necessary only to bring the pen to within 15 or 20 lines of chart center. Precise balance is not required, since the accuracy and linearity of the Universal Amplifier are not affected by small unbalances.

8. Turn the SELECTOR switch (Fig. 13) to the "shift phase" position. Turn the CHART MULTIPLIER switch (Fig. 13) "off" and re-adjust the pen to chart center by means of the PEN BIAS control (Fig. 13).
9. Set the CHART MULTIPLIER switch (Fig. 13) in the desired position and adjust the pen to chart center by means of the BALANCE 2 control (Fig. 15) on the LVDT Balance.
10. By displacing the transducer mechanically, test for sensitivity of the system with the SELECTOR switch (Fig. 13) in the "shift phase" position. Note deflection of the oscillograph pen.
11. Turn the SELECTOR switch (Fig. 13) to the "in phase" position. Turn the CHART MULTIPLIER switch (Fig. 13) "off" and adjust the pen to chart center by means of the PEN BIAS control (Fig. 13).
12. Set the CHART MULTIPLIER switch (Fig. 13) in the desired position and adjust the pen to chart center by means of the BALANCE 1 control (Fig. 15) on the LVDT Balance.
13. By displacing the transducer mechanically, test for sensitivity of the system with the SELECTOR switch (Fig. 13) in the "in phase" position and note pen deflection.
14. Set the SELECTOR switch (Fig. 13) in the "in phase" or "shift phase" position, to produce the greater pen deflection for a given change.

CALIBRATION OF THE UNIVERSAL AMPLIFIER FOR USE WITH THE LVDT BALANCE

Because many types of LVDT transducers are in use, no standard calibration procedure can be established for systems using such transducers. Each transducer should be calibrated for its particular application. In general, the amplifier may be calibrated by introducing a known mechanical displacement in the transducer and adjusting the CARRIER GAIN control (Fig. 13) as necessary to relate pen deflection to the known mechanical displacement.

For special information on application of LVDT transducers, contact the Applications Engineering Section, Brush Instruments, Division of Clevite Corporation, 3405 Perkins Avenue, Cleveland 14, Ohio.

NORMAL OPERATION OF THE UNIVERSAL AMPLIFIER WITH THE LVDT BALANCE

1. Adjust the oscillograph pen to any desired zero position on the chart by means of the PEN BIAS control (Fig. 13). Do not use the PEN BIAS control to establish a pen zero position *off* the chart paper.
2. With the transducer circuit complete, and with the system balanced and calibrated as described above, set the VOLTS/CHART LINE switch (Fig. 13) in the "carrier" position, and set the INPUT switch (Fig. 13) in the "grounded" position.
3. Apply load to the transducer circuit and turn the CHART MULTIPLIER switch (Fig. 13) to "1000", "500", etc., to reach the desired sensitivity.

If two or more Universal Amplifiers are being operated simultaneously to record related information, oscillator circuits in the amplifiers should be synchronized. To do this, interconnect the amplifiers through the SYNC connectors (Fig. 1) by means of suitable wiring and the cable connectors supplied with the amplifiers. Pins "A" and "B" on each matching sync input connector (female) should be connected in parallel with pins "A" and "B", respectively, on every other matching sync input connector in the system of amplifiers. When oscillator circuits are synchronized, all interconnected amplifiers must be turned on for operation of *any* of the amplifiers.

OFF-CENTER ZERO OPERATION OF THE UNIVERSAL AMPLIFIER WHEN USED WITH THE LVDT BALANCE

It is sometimes desirable, when the Universal Amplifier is being used with inductive transducers, to expand the dynamic component of a complex signal for more detailed study. It is possible, by adjusting the zero position of the signal off the chart paper, to cancel the static component and magnify the amplitude of the recording representing the dynamic component. This off-center zero operation permits more accurate interpretation of the dynamic signal. Cancellation of the static signal component is accomplished by means of either the BALANCE 1 control or the BALANCE 2 control on the LVDT Balance (Fig. 15) and the CHART MULTIPLIER switch (Fig. 13) in conjunction with the SELECTOR switch (Fig. 13) on the amplifier front panel. The BALANCE 1 control on the LVDT Balance, used with the SELECTOR switch in the "in phase" position, cancels an inphase or resistive component. The BALANCE 2 control on the LVDT Balance, used with the SELECTOR switch in the "shift phase" position, cancels out the quadrature component in the transducer circuit.

With the amplifier balanced, as described under "Balancing the Universal Amplifier for Use with the LVDT Balance Model RA 5222 00," above, proceed with off-center zero operation, as follows:

1. With the transducer in its null position, turn the SELECTOR switch (Fig. 13) to "in phase" or "shift phase" position (set the switch in the position previously determined as the more sensitive). If the sensitivity is the same in the "in phase" and "shift phase" positions, set the SELECTOR switch in the "in phase" position and use the BALANCE 1 control (Fig. 15).
2. Turn the CHART MULTIPLIER switch (Fig. 13) to "off".
3. Apply the complex load signal to be studied, and turn the CHART MULTIPLIER switch (Fig. 13) to "1000", "500", etc., until the oscillograph pen is off the edge of the chart paper; turn the switch back to the last previous setting.
4. With the appropriate BALANCE 1 or BALANCE 2 control on the LVDT Balance (Fig. 15), adjust the pen trace until the pen records equal amplitudes of the dynamic signal component either side of chart center.
5. Turn the CHART MULTIPLIER switch (Fig. 13) to a more sensitive position ("200", "100", etc.) to increase the amplitude of the dynamic signal component as recorded on the chart.
6. If necessary, re-adjust the recording of the dynamic signal component to the center of the chart by means of the appropriate BALANCE 1 or BALANCE 2 control, as described in step 5, above.

The gain and linearity of the amplifier are not affected if the static component cancellation at any CHART MULTIPLIER switch setting is within the range of the BALANCE 1 and BALANCE 2 controls on the LVDT Balance (Fig. 15).

OPERATION AS A MEDIUM GAIN D. C. AMPLIFIER

In addition to use with the Bridge Balance Model RA 5212 00 and the LVDT Balance Model RA 5222 00, the Brush Universal Amplifier is suited for use as a medium gain d.c. amplifier. In such application, the d.c. amplifier section alone is used, while the carrier amplifier section remains idle.

SINGLE-ENDED AND BALANCED INPUT SIGNALS APPLIED TO THE D.C. AMPLIFIER SECTION

The d.c. amplifier section of the Universal Amplifier will accept either single-ended or "balanced" input signals. A single-ended signal is obtained from a circuit having one terminal already at ground potential, or a circuit which will not be disturbed if one terminal is connected to ground or to the amplifier chassis.

A "balanced" or double-ended signal, as used in connection with the d.c. amplifier section, is a signal obtained from a circuit which will be disturbed when one terminal is connected to ground. For example, the voltage across the secondary winding of a transformer with an intermediate tap connected to ground may be defined as a "balanced", or double-ended signal. Grounding of either output terminal of such a circuit would short circuit the transformer.

Examples of single-ended and "balanced" input connections are shown in Figure 17.

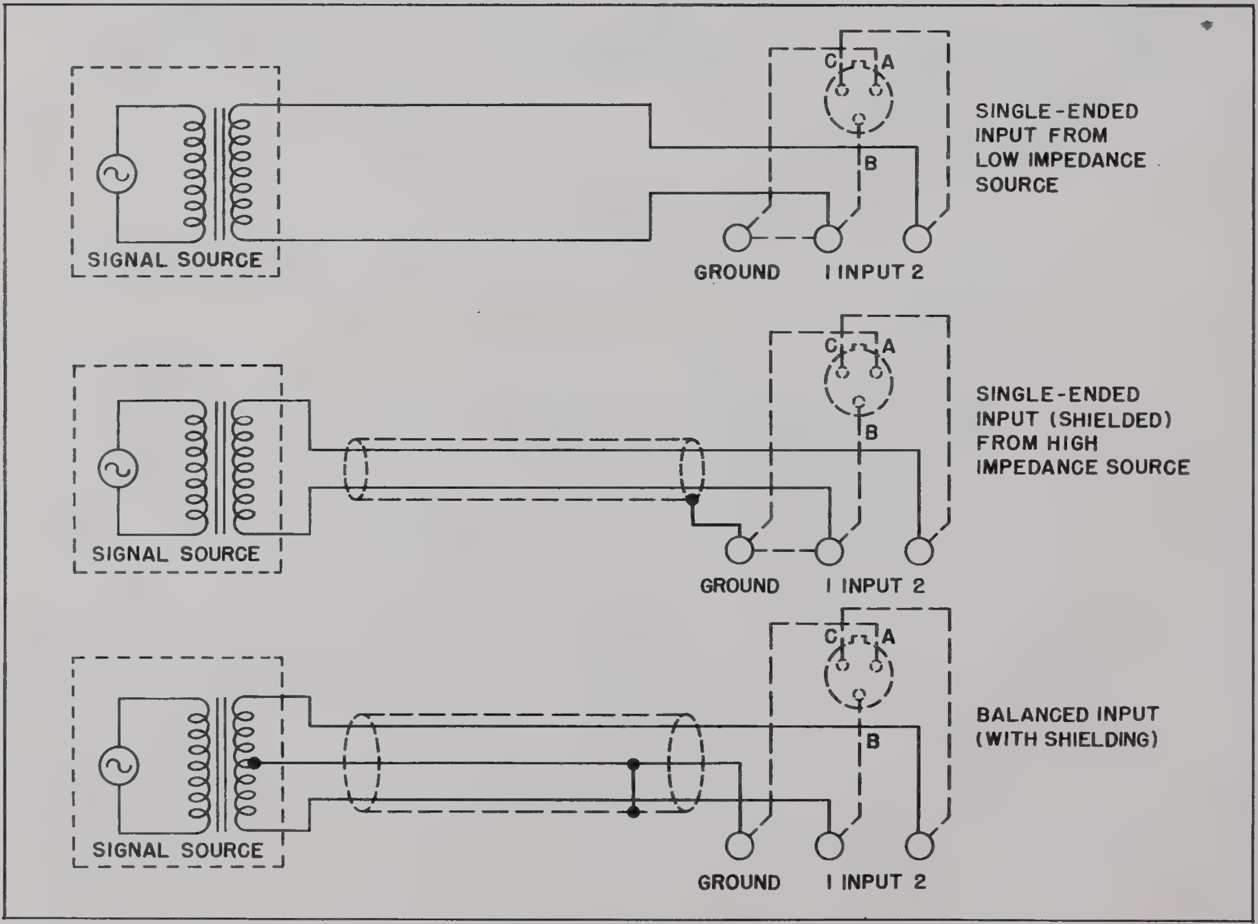

C
A
B
SINGLE-ENDED INPUT FROM LOW IMPEDANCE SOURCE
SIGNAL SOURCE
GROUND
1 INPUT 2
C
A
B
SINGLE-ENDED INPUT (SHIELDED) FROM HIGH IMPEDANCE SOURCE
SIGNAL SOURCE
GROUND
1 INPUT 2
C
A
B
BALANCED INPUT (WITH SHIELDING)
SIGNAL SOURCE
GROUND
1 INPUT 2

Fig. 17. Typical Single-Ended and Balanced Signal Sources.

When one side of the signal circuit is connected to ground a considerable distance from the amplifier input and the signal level is low, it is possible that "ground currents" through the "ground" connection to the amplifier will produce sufficient voltage drop between the signal source and the amplifier to introduce spurious signals. In such a case it is advisable to set the INPUT switch in the "balanced" position and use the "balanced" input terminals (INPUT 1 and INPUT 2) with one terminal connected to ground at the signal source as shown in Figure 18. Such connections eliminate the "ground loop" in the input circuit.

USE OF THE D.C. AMPLIFIER SECTION WITH AN OSCILLOSCOPE

When the d.c. amplifier section is used with an oscilloscope or similar equipment, amplifier output is taken from pins "B" and "C" of the OUTPUT connector on the rear panel (Fig. 1).

WARNING:

The output terminals of this amplifier are 30 volts (d.c.) above chassis and should not be connected to any load in which either terminal is grounded.

In cases where extended frequency response is desired (when the d.c. amplifier section is being used with an oscilloscope or similar equipment), turn the PEN COMPENSATION control (Fig. 1) fully counterclockwise, noting that a switch is actuated at the full counterclockwise position. The voltage gain of the amplifier, when the PEN COMPENSATION control is in full counterclockwise position, is in excess of 30.

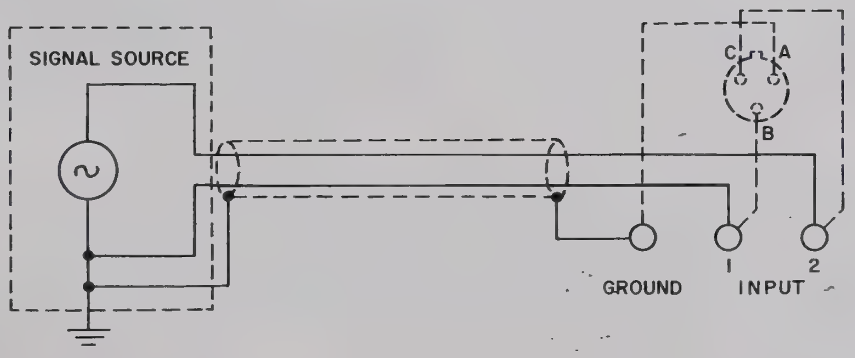


Fig. 18. Connection of Single-Ended Input from Remote Signal Source.

CALIBRATION OF THE D.C. AMPLIFIER SECTION

After balancing the d.c. amplifier section and matching it with a penmotor (see "Frequency Compensation", above), calibrate the d.c. amplifier section as follows:

1. Turn the VOLTS/CHART LINE switch (Fig. 13) "off" and set the INPUT switch (Fig. 13) in the "balanced" position. If the oscillograph pen is not on the center line of the chart, repeat the procedures described under "Balancing the D.C. Amplifier Section", above.
2. Turn the VOLTS/CHART LINE switch (Fig. 13) to the "calibrate" position and adjust the CALIBRATION control (Fig. 13) as necessary to obtain a pen deflection of 20 chart lines left of center. Turn the VOLTS/CHART LINE switch to "off".
3. Check 20 line deflection by again turning the VOLTS/CHART LINE switch (Fig. 13) to the "calibrate" position. If necessary, readjust the CALIBRATION control (Fig. 13) to obtain a pen deflection of 20 chart lines.

PRELIMINARY OPERATION OF THE D.C. AMPLIFIER SECTION

Connect the d.c. amplifier section to a signal source of known amplitude by means of the GROUND, INPUT 1, and INPUT 2 terminals (Fig. 13) on the front panel, or by means of the D.C. INPUT connector (Fig. 1) on the rear panel, using shielded leads when the impedance of the signal source is high.

When connecting a single-ended input at the front panel, connect the "hot" side (in reference to ground) to the INPUT 2 terminal (Fig. 13). Connect the side of the signal to be grounded to the GROUND terminal (Fig. 13) or the INPUT 1 terminal (Fig. 13).

When connecting a single-ended input at the rear panel, connect the "hot" side of the signal to pin "C" of the D.C. INPUT connector (Fig. 1), and connect the side of the signal to be grounded to pin "B" or pin "A". (When the INPUT switch is in the "grounded" position, pin "B" is shorted to pin "A", so that either pin may be used as a ground connection.)

To connect a balanced input at the front panel, connect one side of the input circuit to the INPUT 1 terminal (Fig. 13), and the other side to the INPUT 2 terminal (Fig. 13). To connect a balanced input at the rear panel, connect one side of the input circuit to pin "B" of the D.C. INPUT connector (Fig. 1), and the other side to pin "C". The ground point of the signal source, if available, as well as signal cable shielding, should be connected to the GROUND terminal on the front panel, or to pin "A" of the D.C. INPUT connector on the rear panel.

NORMAL OPERATION OF THE D.C. AMPLIFIER SECTION

1. Turn the VOLTS/CHART LINE switch (Fig. 13) successively to "10", "5", etc., to reach the desired sensitivity. The signal voltage is equal to the number of lines of pen deflection, from the signal zero position, multiplied by the setting of the VOLTS/CHART LINE switch.
2. Adjust the oscillograph pen to the desired position on the chart paper by means of the PEN BIAS control (Fig. 13) if the INPUT switch (Fig. 13) is in the "grounded" position. No adjustment can be made if the INPUT switch is in the "balanced" position. See " Balancing the D.C. Amplifier Section", above.

OFF-CENTER ZERO OPERATION OF THE D.C. AMPLIFIER SECTION
(When using single-ended input only)

It is often desirable to expand the recording of a small dynamic signal superimposed on a larger d.c. voltage for close examination. In such cases, the PEN BIAS control (Fig. 13) may be used, in conjunction with the VOLTS/CHART LINE switch (Fig. 13) for electrical displacement of the pen zero reference position as much as 200 lines either side of chart center. (Such signal expansion is possible only when a single-ended input is used.)

To expand the dynamic portion of a complex signal for more convenient study, proceed as follows:

1. Calibrate the recording system as described under "Calibration of the D.C. Amplifier Section", above. The CALIBRATION, or gain control (Fig. 13), once set, should not be moved during the study of the dynamic signal.
2. With the VOLTS/CHART LINE switch (Fig. 13) in the "10" position, center the oscillograph pen on the chart paper by means of the PEN BIAS control (Fig. 13).
3. Turn the VOLTS/CHART LINE switch (Fig. 13) to "5", "2", etc., until a satisfactory pen deflection is noted.
4. Note the number of lines of pen deflection representing the static component of the complex signal, where

$$\begin{array}{c}\text{VOLTS/CHART LINE}\\ \text{SWITCH SETTING}\end{array} \times \begin{array}{c}\text{AVERAGE PEN}\\ \text{DEFLECTION}\end{array} = \begin{array}{c}\text{STATIC COMPONENT}\\ \text{OF SIGNAL VOLTAGE.}\end{array}$$

5. Using the PEN BIAS control (Fig. 13), move the recording of the dynamic signal across chart center to the opposite edge of the chart.
6. Repeat steps 3 and 5, above, until the recording of the dynamic signal can no longer be moved across chart center by operation of the PEN BIAS control (Fig. 13). Maximum accuracy of recording will be obtained when the dynamic signal is centered on the chart.
7. The amplitude of the dynamic component can then be determined by the formula

$$\begin{array}{c}\text{VOLTS/CHART LINE}\\ \text{SWITCH SETTING}\end{array} \times \begin{array}{c}\text{DYNAMIC PEN}\\ \text{DEFLECTION}\end{array} = \begin{array}{c}\text{DYNAMIC COMPONENT}\\ \text{OF SIGNAL VOLTAGE.}\end{array}$$

The Universal Amplifier Model RD 5612 00 consists basically of an oscillator and a carrier preamplifier section, with a choice of balance boxes (Bridge Balance Model RA 5212 00 and LVDT Balance Model RA 5222 00) for accommodation of different types of transducers; a d.c. amplifier section, for use of the Universal Amplifier with a Brush oscillograph; and a power supply (Fig. 19).

The carrier preamplifier section permits the measurement of low frequency phenomena through the use of a modulated carrier system. The transducer in use is excited by a 2 kc signal from a sine wave oscillator in the Universal Amplifier. The carrier signal is amplitude modulated in proportion to changes in the level of the signal being measured. This modulated transducer output signal is fed through an a.c. amplifier into a phase sensitive demodulator for detection of signals representing the phenomena being measured. The phase sensitive demodulator demodulates the carrier signal and senses positive or negative portions of the input signal, giving an output varying in proportion to the modulated carrier signal. Terminals are provided for connection of the demodulated output to an oscilloscope or similar instrument, if desired.

The d.c. amplifier section amplifies the demodulated output of the carrier preamplifier section to the level required for driving a Brush oscillograph penmotor. If desired, the d.c. amplifier section may be used as a medium gain d.c. amplifier. A separate input circuit, provided for this type of operation, permits selection of single-ended or balanced input signals, attenuates signal voltages, and connects calibration or pen bias voltages to the d.c. amplifier section. The output circuit of the d.c. amplifier section carries amplified signals to the oscillograph, and applies negative feedback to stabilize overall gain in the amplifier section. An adjustment in the output circuit permits changing of the amplifier frequency response to complement that of the penmotor, producing optimum response in the amplifier-oscillograph combination.

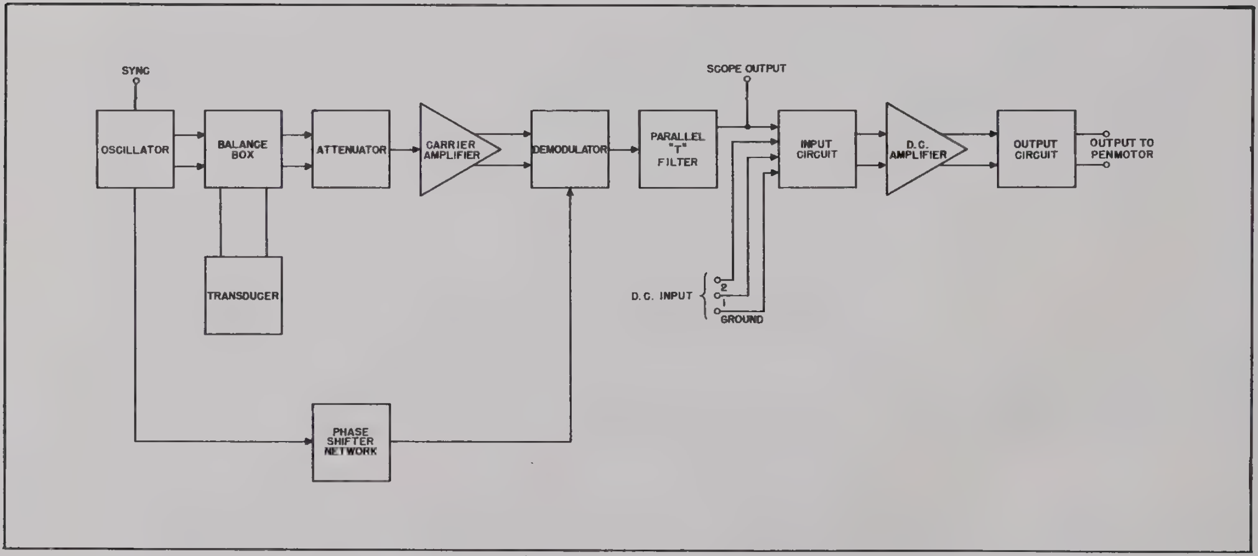


Fig. 19. Block Diagram—Universal Amplifier Model RD 5612 00.

CARRIER PREAMPLIFIER SECTION

The carrier preamplifier section includes a 2 kc sine wave oscillator circuit, a choice of balance boxes for accommodation of different types of transducers (Bridge Balance Model RA 5212 00 and LVDT Balance Model RA 5222 00), a carrier amplifier section, a phase sensitive demodulator section, a phase shifter network, and an output filter network.

OSCILLATOR

The oscillator, operating at 2 kc, consists of a 12AU7 tube with a tuned circuit between the grid and the cathode. Cathode current of the oscillator flows through the primary winding of transformer T-1 (Fig. 20). Transformer output is coupled to the transducer through the appropriate balance box. Output voltage from the oscillator cathode is also used to drive the demodulator (described below). When a number of Universal Amplifiers are operated together, oscillator circuits must be synchronized to prevent interaction, in the transducer leads, between oscillator signals at slightly different frequencies. A connector on the rear of the amplifier permits the center of the oscillator tuned circuit to be connected to corresponding points in other Universal Amplifiers.

The plug-in balance boxes connect the oscillator output to the transducer, provide a means of compensating for transducer unbalance conditions, and connect transducer output to the amplifier.

BRIDGE BALANCE

The Bridge Balance Model RA 5212 00 (Fig. 21) is a 4-terminal Wheatstone bridge network, which adapts the amplifier for use with strain gages. The circuit may use one, two, or four variable elements in its four arms.

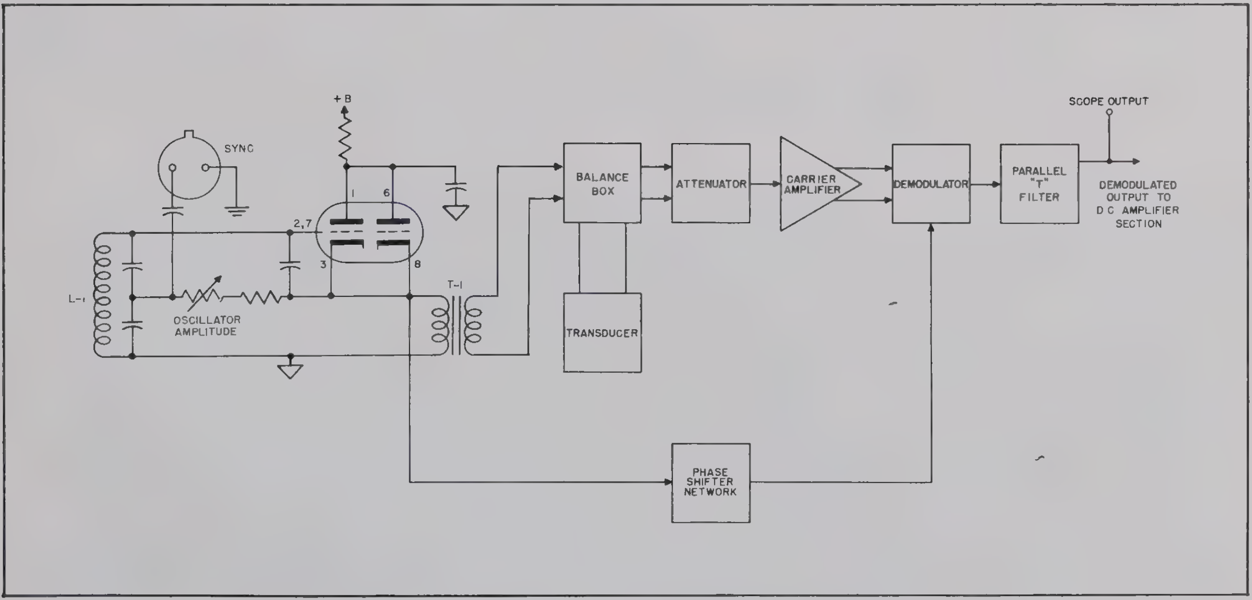


Fig. 20. Block Diagram—Carrier Amplifier Oscillator Circuit.

The output voltage of the oscillator is fed into two balance potentiometers (BALANCE 1 and BALANCE 2) and to terminals 1 and 4 of the bridge circuit. Terminal 3 of the bridge circuit is grounded, and the output voltage of the bridge circuit is taken from pin 2. This output voltage is summed with two voltage components derived from the balance potentiometers. The BALANCE 1 potentiometer introduces a resistance to compensate for resistive unbalance in the bridge circuit; the BALANCE 2 potentiometer, in conjunction with capacitors, offers a variable capacitance to compensate for capacitive unbalance in the circuit. The combined effect of the two controls is to produce zero signal output from the bridge circuit when no load is applied to the transducers.

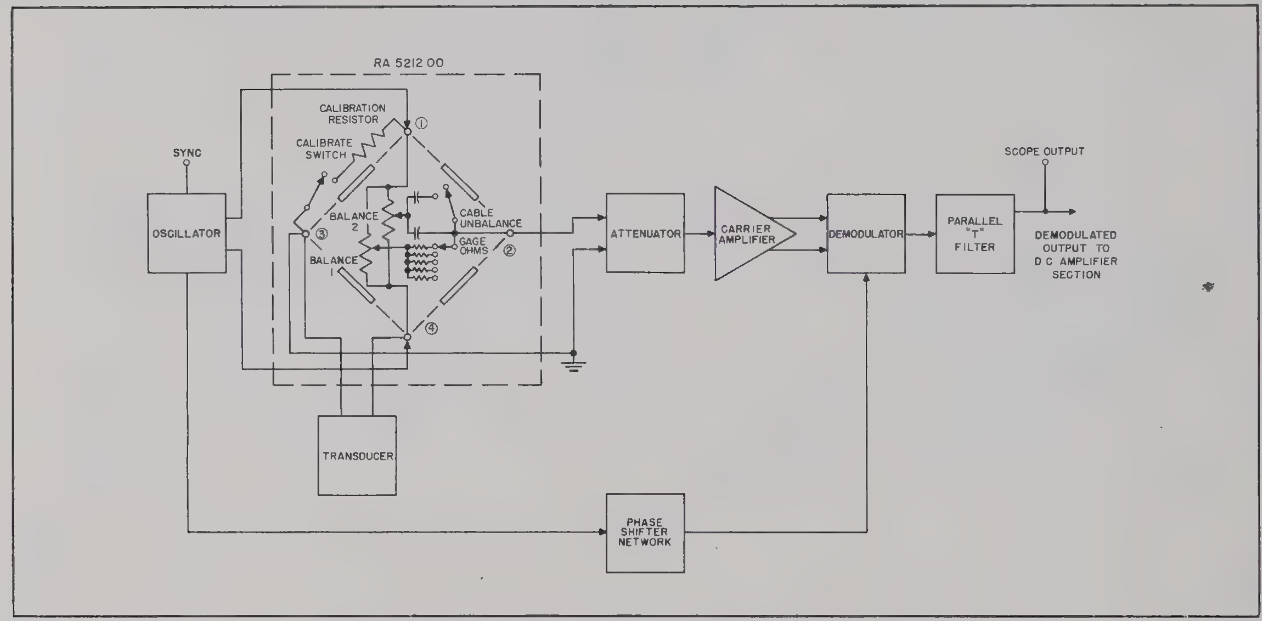


Fig. 21. Block Diagram—Bridge Balance Model RA 5212 00.

Controls on the rear of the Bridge Balance are used to adjust the sensitivity of the balance potentiometers. The GAGE OHMS switch connects a resistor of appropriate value in series with the BALANCE 1 control, with the value of the resistor selected depending on the resistance value of the strain gage in use. (When strain gages of higher resistance value are used, the GAGE OHMS switch must be set at a higher range.) The CABLE UNBALANCE switch permits variation of the capacitance in series with the BALANCE 2 control. When relatively short strain gage leads are used, the CABLE UNBALANCE switch is set at "short", and only one capacitor is connected in series with the BALANCE 2 potentiometer; when longer leads are used, the switch is set at "long" and a second capacitor, in parallel with the first, is connected in series with the BALANCE 2 potentiometer. The effect of this variation in capacitance is to produce zero output voltage from the bridge circuit when the transducers are not under load.

A 390K CALIBRATION RESISTOR and switch, connected between terminals 1 and 3, provide for calibration of the strain recording system. When the switch is closed, the 390K CALIBRATION RESISTOR is connected in parallel with one active arm of the bridge circuit, introducing a known change in resistance (equivalent to a known strain) in that arm; a known output is thus obtained from the bridge circuit for calibration of the Universal Amplifier.

LVDT BALANCE

The LVDT Balance Model RA 5222 00 (Fig. 22) is a 3-terminal network which permits use of LVDT (linear variable differential transformer) transducers with the Universal Amplifier.

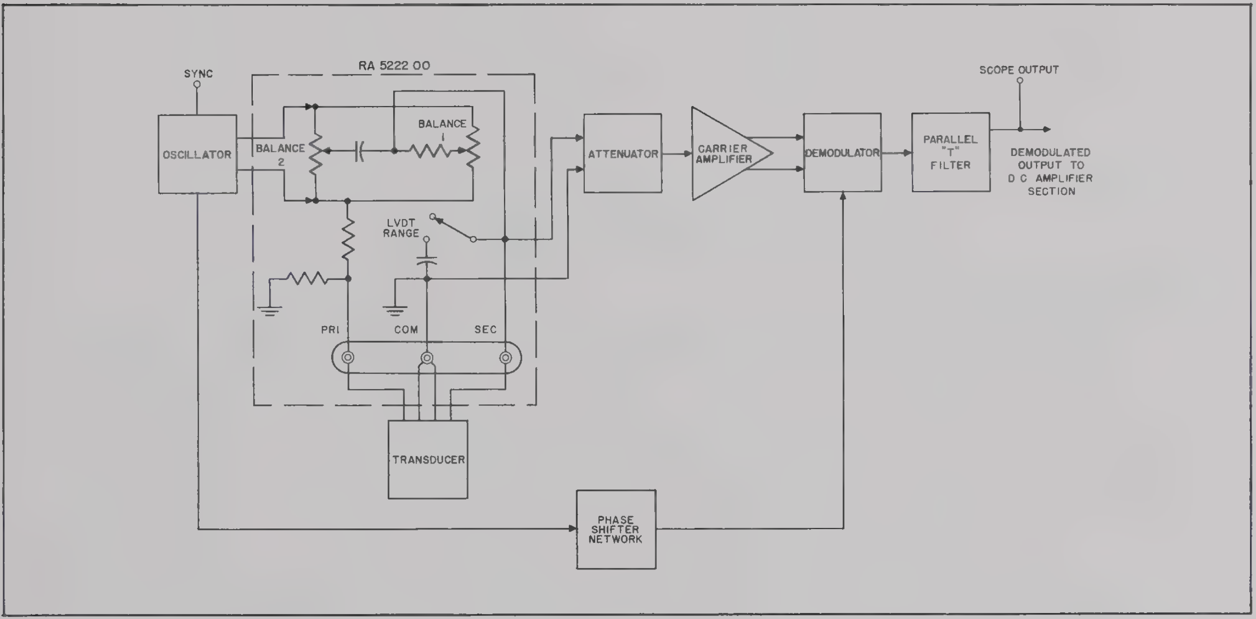


Fig. 22. Block Diagram—LVDT Balance Model RA 5222 00.

The LVDT Balance Model RA 5222 00 performs the same general function in connection with LVDT transducers as that performed by the Bridge Balance Model RA 5212 00 in connection with strain gages. The BALANCE 1 and BALANCE 2 potentiometers introduce resistance and capacitance, respectively, to compensate for inherent resistive or capacitive unbalance in the transducer circuit.

In the "balanced" condition, the LVDT Balance and transducer circuit will produce zero output when no load is applied to the transducer. Any displacement of the movable element of the transducer will produce a 2 kc signal proportional in amplitude to the displacement of the movable element.

The LVDT RANGE switch, on the back of the LVDT Balance, permits adjustment of the transducer sensitivity range. When the switch is closed, a capacitor is connected from one transducer lead to ground, thus lowering the impedance of the circuit receiving signals from the transducer, and reducing the sensitivity of the amplifier.

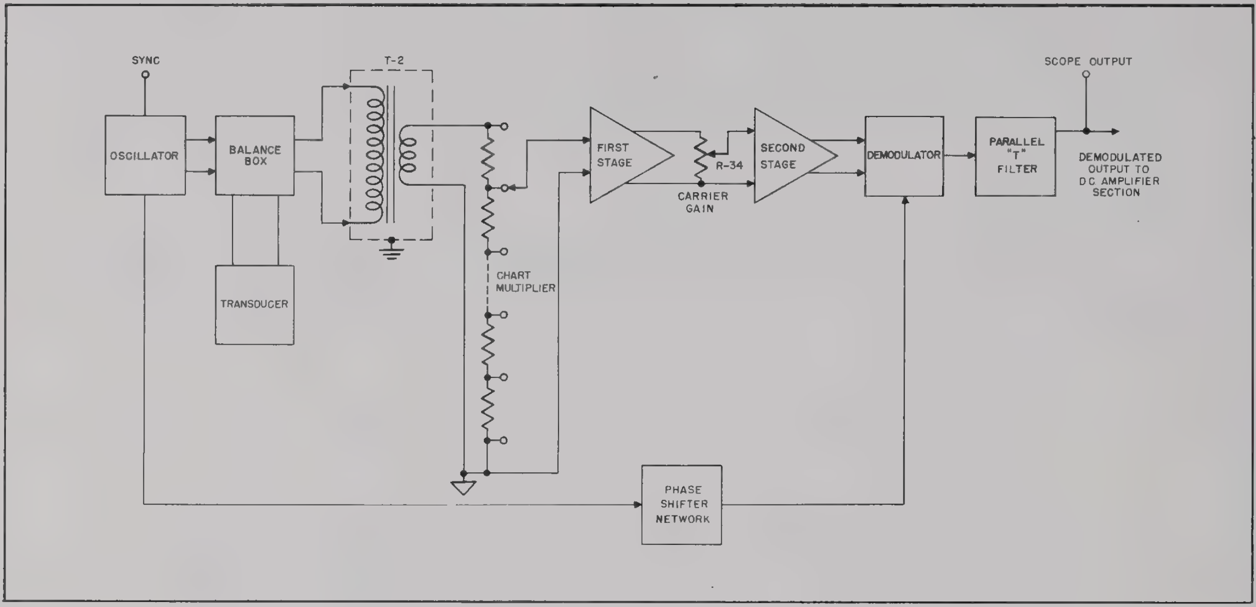


Fig. 23. Block Diagram—Carrier Amplifier Circuit.

CARRIER AMPLIFIER

Output voltage from the balance box is coupled from the summing point to the primary winding of the input transformer T-2 (Fig. 23). Secondary voltage from this transformer is fed through an attenuator and amplified in two sections of a 12AX7 tube (V-2), which is used as an R-C coupled amplifier with heavy negative feed back. Output (plate) voltage from the 12AX7 tube is coupled to the carrier gain potentiometer (R-34), which serves as a continuous gain control. Voltage taken from the arm of the carrier gain potentiometer is further amplified in two sections of a 12AT7 tube (V-3). Output (plate) voltage from the 12AT7 tube is applied to the primary winding of the demodulator transformer (T-3).

PHASE SENSITIVE DEMODULATOR

The function of the demodulator (Fig. 24) is to demodulate the amplified carrier signal received from the carrier amplifier section. The demodulator circuit used in the Universal Amplifier is linear over a very wide range, providing a high degree of overall accuracy in the amplifier. Output of the demodulator is coupled to the pen drive amplifier section through the VOLTS/CHART LINE attenuator switch, provided the switch is in the "carrier" position.

The demodulator compares two voltages (each at 2 kc). One, the signal voltage, is the amplified output of the transducer, appearing across the secondary winding of the demodulator transformer (T-3). The second (driving or reference voltage), appearing at the center tap of the demodulator transformer secondary winding, is derived from the oscillator output. This voltage may be either inphase or 90° out of phase, with respect to the oscillator output voltage. A selector switch (Fig. 25) allows coupling of this reference voltage to the demodulator, either directly or through a 90° phase shift network. The algebraic summation of signal and reference voltages which appear at the plate (Pin 2) and the cathode (Pin 1) of the 6AL5 tube (V-4) determine which section of the tube is conducting and charging capacitors C-23 and C-24.

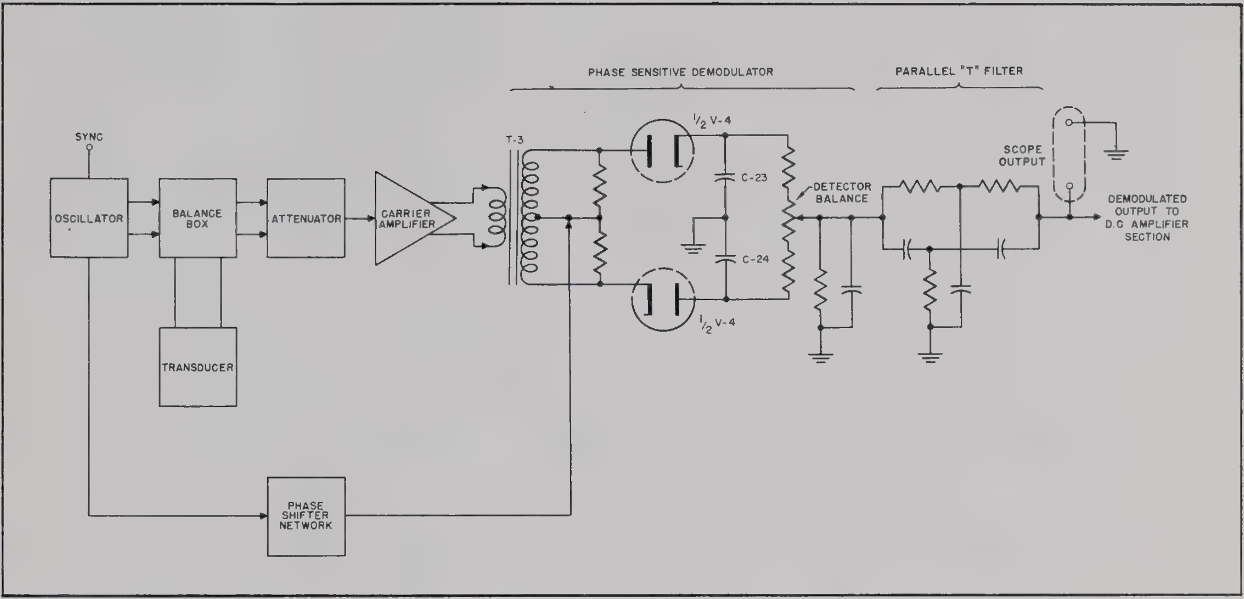


Fig. 24. Block Diagram—Demodulator Circuit.

During one half cycle (if the signal and reference voltages are in phase), a plate voltage of $\left(e_1 + \frac{e_2}{2}\right)$ volts will appear in the proper polarity for conduction across one diode section, where

e_1 = Reference Voltage,
e_2 = Signal Voltage, and
$e_1 > \frac{e_2}{2}$.

During the next half cycle, a voltage of $\left(e_1 - \frac{e_2}{2}\right)$ volts will appear across the other diode section in proper polarity for conduction. Thus, the charges on capacitors C-23 and C-24 will be unequal and opposite in sign, so that a voltage other than zero will appear at the arm of the detector balance potentiometer. Further, the voltage at this point is directly proportional to the amplitude of the signal voltage.

When reference voltage and signal voltage are 180° out of phase, the voltage appearing at the arm of the detector balance potentiometer will be opposite in polarity to the voltage derived from the inphase reference and signal voltage components described above. Thus the demodulator can determine the polarity of the signal from the transducer. For example, in strain gage measurements, the demodulator output voltage reverses polarity as the load on the member under test is changed from tension to compression.

A 2 kc parallel "T" filter network reduces any remaining 2 kc (carrier) component in the demodulator output, permitting a clear display of the demodulated signal. Frequency response at the filtered output is down no more than 3 db at 200 cps. The filtered output may be connected to an oscilloscope through the DEMODULATED OUTPUT terminals, or fed through the d.c. amplifier section and recorded by an oscillograph.

PHASE SHIFTER NETWORK

If the signal voltage and the reference voltage applied to the demodulator are exactly 90° out of phase, it can be shown that, during each cycle, the voltages appearing across each diode section of the 6AL5 tube (V-4) of proper polarity for conduction are of equal amplitude and are applied for equal periods. As a result, the charges on capacitors C-23 and C-24 will be of equal amplitude and opposite polarity; no voltage, then, will appear at the arm of the detector balance potentiometer. Also, it can be shown that when the amplitude of the reference voltage is considerably greater than that of the signal voltage (which is usually the case in the Universal Amplifier), variation of output voltage amplitude is in direct proportion to the cosine of the phase angle between signal and reference voltages. A phase shifter network (Fig. 25) in the reference voltage circuit permits the phase angle of the reference voltage to be shifted 90°. The proper reference voltage phase may be determined by testing the carrier system with the transducer being used, to find which setting of the selector switch produces the greater system sensitivity.

The transducer balancing operation is performed with the selector switch in the "Balance" position. In this case, the signal voltage is used also as the reference voltage, so that unequal charges are applied to capacitors C-23 and C-24. Thus, operation of the BALANCE 1 and BALANCE 2 controls on the balance box will cause a variation in the demodulator output voltage. This variation is directly proportional to the existing unbalance. With the SELECTOR switch in the "balance" position, the demodulator is not phase sensitive, and an absolute null can be obtained when complete balance is reached.

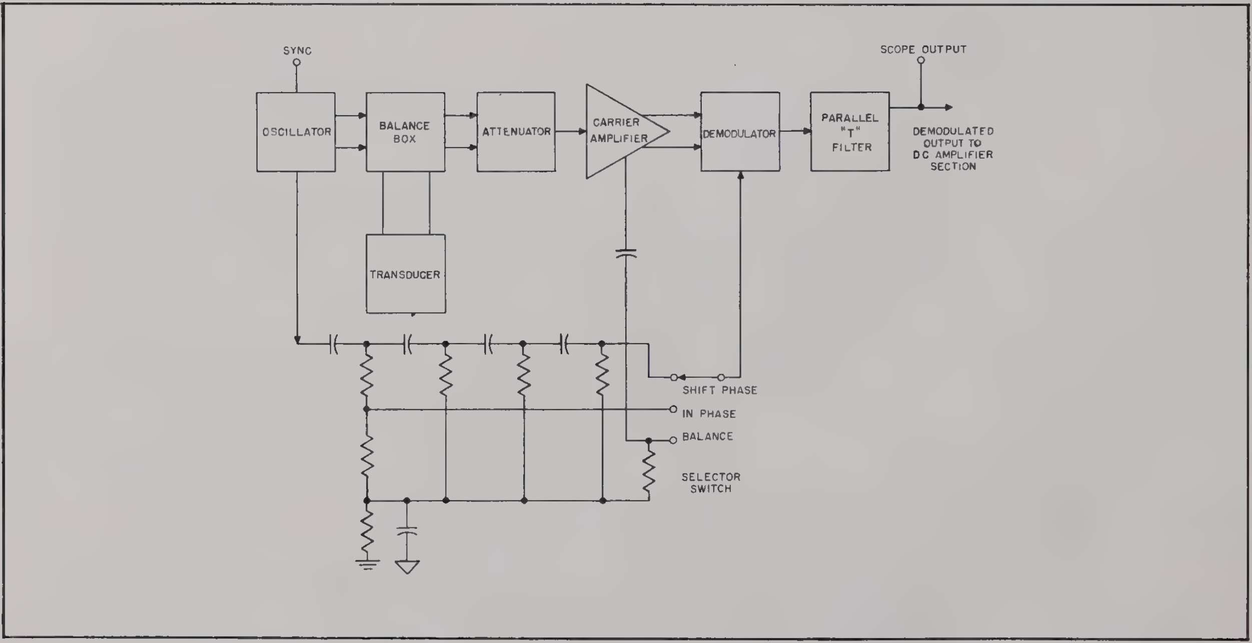


Fig. 25. Block Diagram—Phase Shifter Network.

D. C. AMPLIFIER SECTION

The d.c. amplifier section includes an input circuit, a d.c. amplifier circuit, and an output circuit. The input circuit provides calibration and pen bias voltages for the Universal Amplifier, and attenuates input voltages when the unit is used as a medium gain d.c. amplifier (without the carrier amplifier section). The d.c. amplifier circuit amplifies the demodulated output of the carrier amplifier section (or signals from an external source) to the level required for driving a Brush oscillograph penmotor. The output circuit provides negative feedback for stabilization of amplifier gain. A control in the output circuit permits adjustment of amplifier frequency response to complement that of the associated oscillograph.

INPUT CIRCUIT

The constant resistance attenuator in the input circuit (Fig. 26) provides the means of varying the input level to the first stage of the amplifier circuit. This attenuator always presents a 5 megohm resistance to a single-ended signal source, or a 10 megohm resistance to a balanced signal source throughout the attenuator range. At the first position of the VOLTS/CHART LINE switch (.05 volt per millimeter) the input signal is not attenuated, and the sensitivity of the amplifier circuit is the same as during calibration.

For single-ended ("grounded") operation, input signals are coupled to the amplifier between the INPUT 2 terminal and the GROUND or INPUT 1 terminal. In this case, half of the attenuator is used to couple signals to one grid of the 12AX7 input tube (V-5). A pen bias signal, derived from a mercury cell, is coupled to the other grid of the input tube for positioning the oscillograph pen on the chart, or for providing pen zero displacement. For balanced operation, the dual attenuator couples input signals (connected between INPUT 1 and INPUT 2 terminals) to the grids of the input tube (V-5).

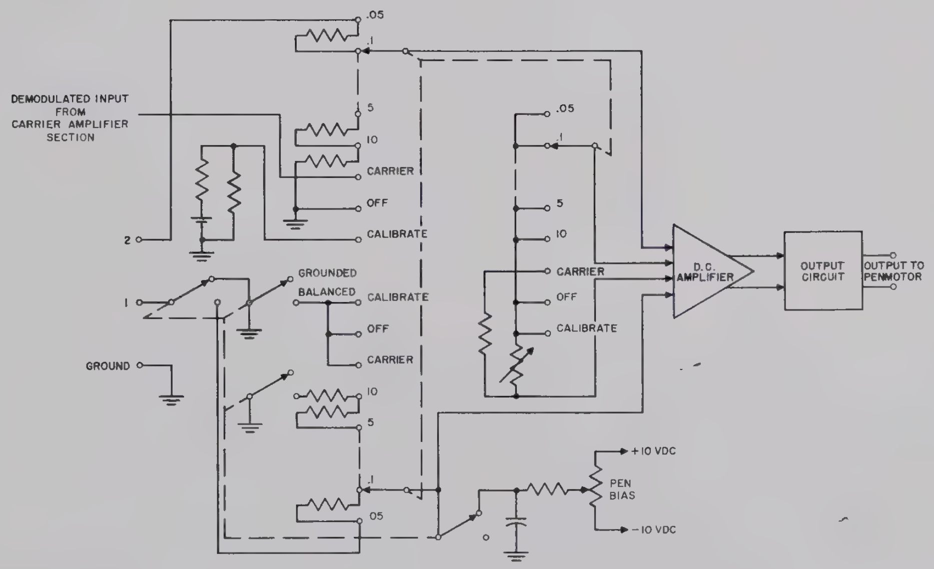


Fig. 26. Block Diagram—Input Circuit (D.C. Amplifier Section).

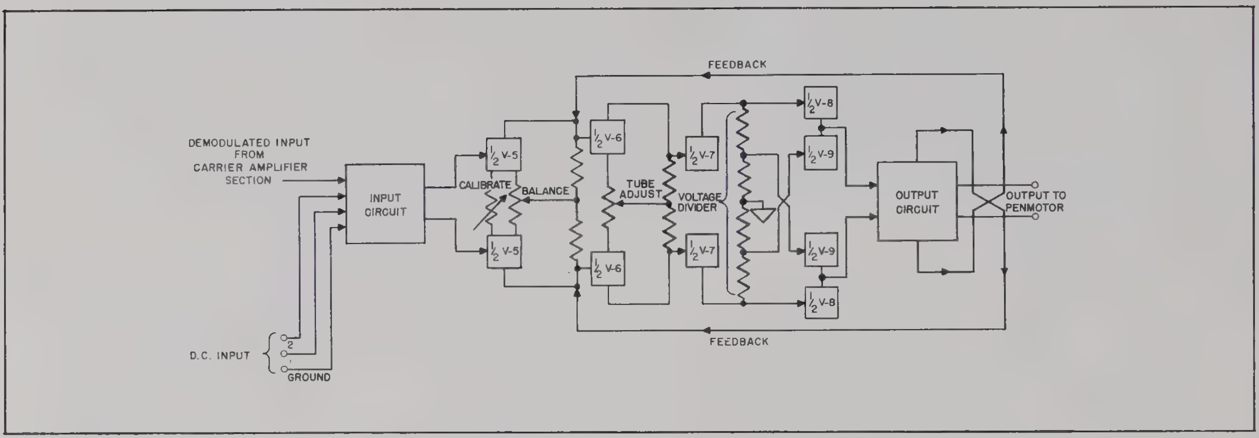


Fig. 27. Block Diagram—D.C. Amplifier Circuit.

D.C. AMPLIFIER CIRCUIT

The input stage of the pen drive amplifier circuit (Fig. 27) consists of a high gain dual triode (V-5) used as a differential d.c. amplifier. The input signal applied to this stage may include an inphase component and a differential component. The inphase component, applied to both input grids of V-5 at the same amplitude and polarity, is an unwanted signal.

Since the input circuit operates as two parallel amplifiers with high cathode degeneration, gain of the inphase component is effectively reduced in the input stage. The desired differential component of the input signal is applied between the two input grids of V-5 with opposite polarities. Since the signal currents flowing through the common cathode resistor are of opposite polarities, no degeneration occurs at that point. As a result, differential voltage gain is not reduced in the first stage.

Gain is controlled by the relatively small "uncommon" cathode degeneration resistance. Variation of this resistance with the gain potentiometer varies degeneration, and thus controls gain of the input stage. If the two tube halves of the input stage are not perfectly balanced, variation of the gain control will produce, in effect, a differential input signal, which is undesirable. Such an effect is eliminated by the "balance" potentiometer adjustment, which provides compensation for tube unbalance. At the plate circuits of the input stage, output voltages are summed with feedback voltages from the amplifier output circuit, and coupled to succeeding amplifier stages.

The second and third stages of the pen drive amplifier channel consist of two high gain dual triodes (V-6, V-7) used as conventional direct-coupled differential amplifiers. A balance control is provided in the second stage, to permit further compensation for tube unbalance in the last three stages of the amplifier circuit.

The third stage tube (V-7) is coupled to a pair of medium gain dual triodes (V-8, V-9), which operate as a bridge output circuit. The sections of each output tube appear at opposite

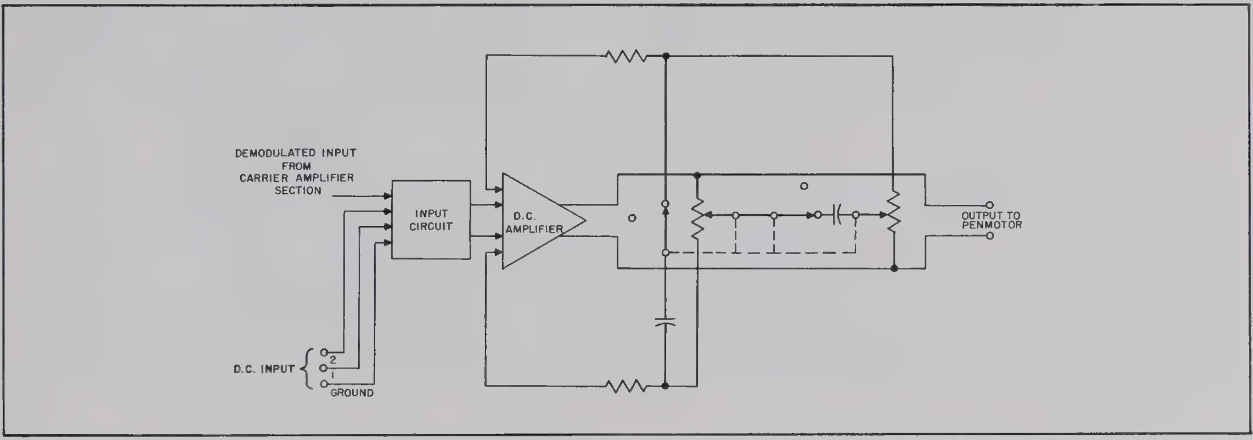


Fig. 28. Block Diagram—Output Circuit. (D.C. Amplifier Section).

arms of the bridge, so that the penmotor coil is, in effect, the load across the bridge. The signals which appear at the input grids of the bridge circuit are equal in amplitude, but opposite in polarity. A voltage divider applies a portion of each bridge input signal to one tube section. This tube section and the tube section receiving the full input signal are on opposite arms of the bridge circuit. (For example, if the full bridge input signal is applied to a grid of V-8, a portion of this same signal is applied to a grid of V-9, on the opposite arm of the bridge circuit.) Application of input voltages to the bridge circuit provides a low impedance series current path through the two tube sections to which positive voltages are applied, and through the penmotor. This causes deflection of the oscillograph pen. Reversing polarity of the input voltages produces a current path through the other two tube sections and through the penmotor. Because the direction of current flow through the penmotor coil has been reversed by the change in polarity of the input signals, the pen is now deflected in the opposite direction.

OUTPUT CIRCUIT

Negative feedback paths from the output terminals of the bridge circuit to the summing points in the plate circuits of the input tube (V-5) provide approximately 26 db of d.c. feedback to stabilize over-all gain in the amplifier circuit (Fig. 28). The a.c. negative feedback around these paths may be reduced with increasing frequency by two capacitors connected across the feedback networks. Compensation of the frequency response of the amplifier to match that of the penmotor is accomplished by varying the effect of one of these capacitors, through the use of a dual potentiometer in the feedback network. A switch is provided on this dual potentiometer to disconnect the two capacitors across the feedback networks. This produces optimum amplifier frequency response from d.c. to 5 kc for use of the d.c. amplifier section with oscilloscopes or other similar devices.

POWER SUPPLY

An electronically-regulated power supply with a wide frequency range is used in the Universal Amplifier Model RD 5612 00, permitting operation from power lines in the frequency range of from 50 to 2000 cps. The power supply provides series-type regulation for plate voltage, and also provides an a.c. filament voltage. High voltage from the transformer (T-4) is rectified in a 6BW4 tube (V-10) and applied to the plates of the 6080 series regulator tube (V-11). (The load is connected to the cathodes of the series regulator tube.) This output voltage is compared at the grid (Pin 7) of the 5751 tube (V-12) with voltage from a 6626/OA2WA reference tube (V-13). This comparison determines whether or not the output voltage of the + B supply agrees with the desired voltage, as preset on the potentiometer (R-129). If not, a voltage change proportional to the error appears at the plate (Pin 6) of the 5751 tube. This voltage is amplified by the other section of the 5751 tube and applied as a bias voltage to the 6080 series regulator tube. This correcting action is continuous, regulating the output voltage of the power supply for varying conditions of load and input voltage.

The + B output of the power supply is connected to the — B output by a voltage divider (R-133, R-134, R-135, and R-136), which establishes the potential from —B to chassis ground for operation of the double-ended amplifier system (carrier amplifier and d.c. amplifier sections). This voltage divider also provides pen bias voltage used for positioning the oscillograph pen. Filament voltages for the amplifier system are derived from transformers* T-4 and T-5. An interference filter, located at the power input of the power supply, minimizes the effect of any transients present in the power line.

This amplifier has been balanced and adjusted accurately before shipment from the factory, and should give long, trouble-free service. For any servicing other than that described in this manual, the instrument should be sent to one of the Brush service facilities (listed on the Warranty page), where it can be restored to original condition. See Shipping Instructions following the Table of Contents.

TUBE REPLACEMENT

To replace any faulty tube, disconnect all cables and expose the chassis. If the amplifier is in a Portable Case, remove screws from the top and bottom of the case, and remove the mounting screws from the front panel of the amplifier. If the amplifier is rack mounted, remove the mounting screws from the front panel, withdraw the amplifier from the rack, and remove the top portion of the wrap-around cover. Do not remove screws securing the front panel to the amplifier chassis. In either case, all tubes will be exposed (Fig. 29).

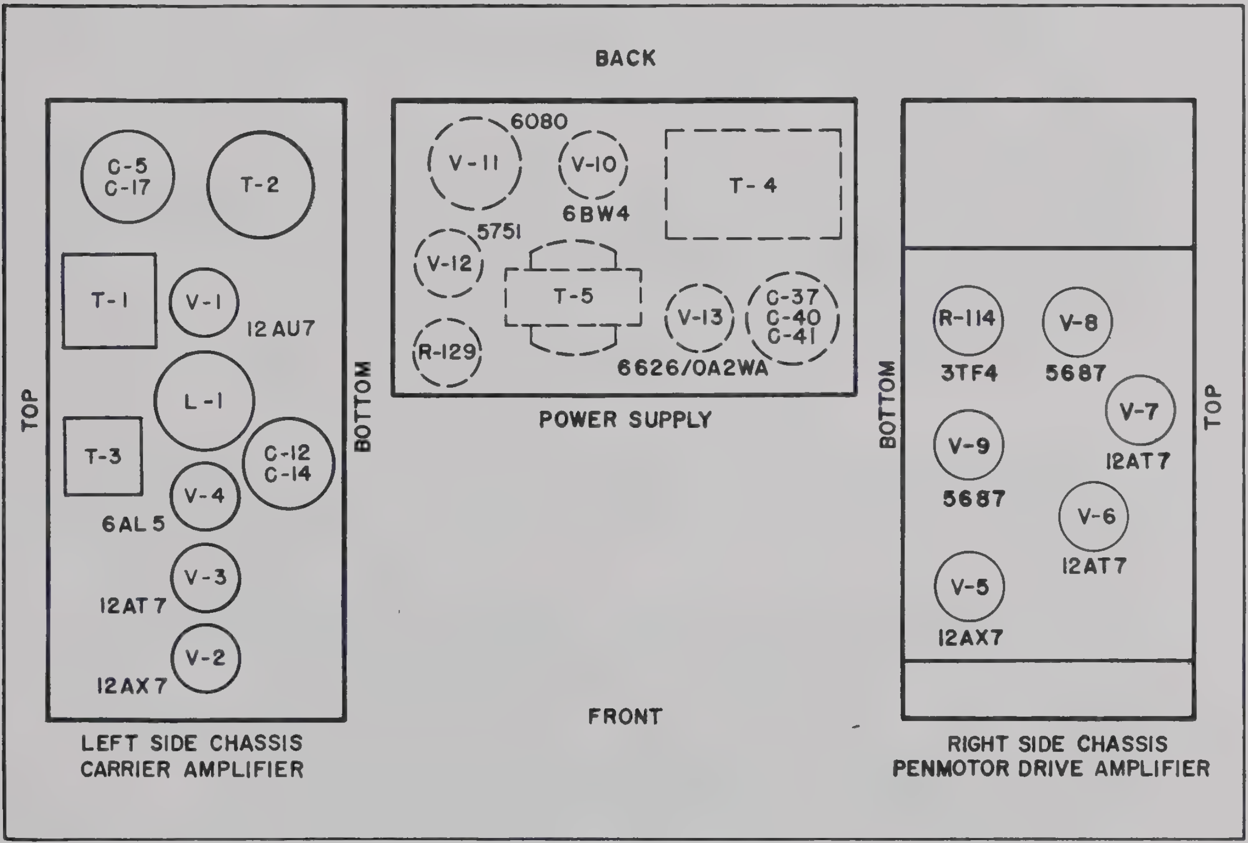


Fig. 29. Tube Layout.

LEFT SIDE CHASSIS

If any tubes are replaced in the left side chassis, rebalance the carrier amplifier section as described under "Carrier Detector Balance Adjustment", below.

RIGHT SIDE CHASSIS

Following the replacement of any tube in the d.c. amplifier section, the amplifier must be balanced, as described below:

1. Connect the OUTPUT connector of the amplifier (Fig. 1) with the oscillograph input connector by means of the amplifier-to-oscillograph signal cable.
2. Connect the amplifier and oscillograph to their power source, and turn the amplifier POWER switch (Fig. 13) to "on". Allow 15 minutes for the amplifier to warm up.
3. Turn the oscillograph "on" at slow chart paper speed (to conserve chart paper).
4. Set the INPUT switch (Fig. 13) in the "balanced" position.
5. Turn the CALIBRATION control (Fig. 13) full clockwise, and bring the oscillograph pen approximately to chart center by means of the TUBE ADJUST control on the rear panel of the amplifier (Fig. 1).
6. Turn the BALANCE control, on the rear panel of the amplifier (Fig. 1), to its extreme counterclockwise position. Rapidly rotate the CALIBRATION control (Fig. 13), counterclockwise, then clockwise, while turning the BALANCE control slowly clockwise until no pen deflection is noted.
7. Center the pen on the chart by means of the TUBE ADJUST control on the rear panel of the amplifier (Fig. 1).

POWER SUPPLY CHASSIS

Following the replacement of any tube in the power supply chassis (Fig. 29), adjust +B voltage to 235 volts by means of the potentiometer control R-129 (measured from the junction of C-38 and R-130 to pin 5 of the 6626/OA2WA tube V-13).

Following any tube replacement in the Universal Amplifier, install the wrap-around cover (if any) on the amplifier, and return the amplifier to its rack or Portable Case.

CARRIER LEVEL ADJUSTMENT

Oscillator output amplitude may be adjusted, if necessary, by means of the OSCILLATOR AMPLITUDE control on the rear panel of the Universal Amplifier (Fig. 1). If the Bridge Balance Model RA 5212 00 (Fig. 4) is used, oscillator output voltage should be 3.0 volts (RMS) measured across terminals 1 and 4 of the Bridge Balance. If the LVDT Balance Model RA 5222 00 (Fig. 15) is used, oscillator output voltage should be 180 mv (RMS) measured across the "primary" and "common" terminals of the LVDT Balance. The above measurements should be made with a Ballantine vacuum tube voltmeter (VTVM) or equivalent.

CARRIER DETECTOR BALANCE ADJUSTMENT

The carrier amplifier detector reference level is adjusted at the factory. However, after a tube change or after a change in the type of balance box used with the amplifier, excessive pen offset may be noted as the SELECTOR switch (Fig. 13) is turned from the "balance" position to the "in phase" or the "shift phase" position. To eliminate such pen offset, re-adjust the detector reference level, as follows:

1. Balance the amplifier as described under "Balancing the Universal Amplifier for Use with the Bridge Balance Model RA 5212 00" or "Balancing the Universal Amplifier for Use with the LVDT Balance Model RA 5222 00", above.

2. Turn the CHART MULTIPLIER switch (Fig. 2) to "off".
3. Set the INPUT switch (Fig. 2) in the "grounded" position.
4. Turn the VOLTS/CHART LINE switch (Fig. 2) to "off".
5. Note the position of the pen on the oscillograph chart.
6. Turn the SELECTOR switch (Fig. 2) to the "in phase" position when using the Bridge Balance, or to the "shift phase" *or* "in phase" position when using the LVDT Balance.
7. Turn the VOLTS/CHART LINE switch (Fig. 2) to the "carrier" position.
8. By means of the DETECTOR BALANCE control on the rear panel of the amplifier (Fig. 1), adjust the pen trace to the position noted in step 5, above.

CORRECTION FOR POWER LINE TRANSIENTS

The Brush Universal Amplifier Model RD 5612 00 features an electronically-regulated power supply, heavy decoupling, and an internal interference filter. However, because of the extremely high gain of the carrier amplifier section, line voltage transients, generated by electric typewriters, adding machines, universal motors, etc., may be amplified and recorded. To prevent the recording of such transients, eliminate their source.

Power line transients can often be eliminated by connecting offending electrical equipment to a power line branch separate from the amplifier power source, and locating such equipment at least 20 feet from the amplifier.

Often the effect of line transients on the amplifier can be eliminated through the use of a filter on the transient source. Such a filter might be a fixed capacitor of predetermined optimum value for relays and event markers; an LC (inductance-capacitance) filter network, available commercially, for electric typewriters, adding machines, and universal motors; or a source filter with interference attenuation characteristics appropriate for the specific machine, available from manufacturers of electric typewriters and adding machines.

If transients cannot be eliminated or reduced satisfactorily at their source, line pulse amplitudes can often be reduced by connecting a commercial type interference filter across power line terminals of the amplifiers.

MODIFICATION OF POWER TRANSFORMER CONNECTIONS FOR OPERATION AT 95 TO 115 VOLTS

The Brush Universal Amplifier is normally wired to operate on a power line voltage of from 105 to 125 volts. If the available power source is from 95 to 115 volts, a slight modification in the wiring of the power transformer (T-4) will adapt the amplifier to operation from such a power source. To make this modification, proceed as follows:

1. Disconnect the input power lead and capacitor lead from terminal "3" of the power transformer (T-4). Connect these two leads to terminal "2" of the power transformer. Refer to the Tube Layout (Fig. 29), and to the Schematic Diagram.
2. Re-solder to terminal "3" of the power transformer (T-4) that lead connecting terminal "3" to the separate filament transformer (T-5).

The above modification will be made at the factory if requested at time of ordering.

TROUBLE SHOOTING

The chart below lists symptoms and probable causes of improper operation of the amplifier, or failure of the amplifier to operate, as well as probable remedies for unsatisfactory operating conditions. The conditions described in the chart are for a Universal Amplifier Model RD 5612 00, connected to a correctly adjusted, operating Brush oscillograph, and operating from a 60 cps 115 volt power source. Procedures suggested in the "Remedy" column may be performed by operating personnel.

GENERAL

SYMPTOM	CAUSE	REMEDY
1. Amplifier does not operate; pilot lamp does not light.	a. Power cable disconnected. b. Fuse open. c. POWER SWITCH turned off. d. No line voltage.	a. Connect to power source. b. Replace fuse. c. Turn POWER SWITCH on. d. Connect to proper power source.
D. C. AMPLIFIER SECTION		
1. D.C. Amplifier section inoperative, pilot lamp lights.	a. Defective amplifier-to-oscillograph cable. b. Inoperative 6BW4, 6080, 5751, 12AX7, 12AT7-WA, or 5687 tubes; inoperative 3TF4 resistor.	a. Repair cable. b. Replace tube or resistor.
2. PEN BIAS control inoperative with INPUT switch in "grounded" position and VOLTS/CHART LINE switch in "off" position.	a. 12AX7 tube or 3TF4 resistor inoperative. b. Defective contacts on INPUT switch.	a. Replace defective tube or resistor. b. Clean contacts or replace switch.
3. TUBE ADJUST control on rear panel inoperative during balancing of amplifier per Operating Instructions.	a. 12AX7, 12AT7WA, or 5687 tubes inoperative.	a. Replace defective tubes.
4. BALANCE control on rear panel inoperative during balancing of amplifier per Operating Instructions.	a. 12AX7 tube or 3TF4 resistor inoperative.	a. Replace defective tube or resistor.
5. Oscillograph pen off chart or deflected far to one side.	a. 5687,12AT7WA,or12AX7 tubes inoperative. b. Grounded lead to pen-motor.	a. Replace defective tubes. b. Eliminate ground.
6. Amplifier can be balanced, but drift exceeds ¼ mm of chart per hour.	a. +B voltage supply not regulating properly. b. Excessive line voltage variation. c. 12AX7, 12AT7WA, or 5687 tube intermittent or producing low emission. d. Defective 3TF4 resistor.	a. Refer to "Power Supply" section of this chart. b. Connect amplifier to proper power source. c. Replace defective tube. d. Replace resistor.

SYMPTOM	CAUSE	REMEDY
7. 120 cps output indicated on oscillograph chart without input to amplifier.	a. Filter capacitor defective. b. Shorted 6080 tube. c. Inoperative 6626/OA2-WA tube or 5751 tube.	a. Replace filter capacitor. b. Replace defective tube. c. Replace defective tubes.
8. 60 cps output indicated on oscillograph chart without input to amplifier.	a. Cathode-heater leakage, any tube in d.c. amplifier section.	a. Locate and replace defective tube.
9. Random output indicated on oscillograph chart without input to amplifier.	a. Noisy tube. b. Noisy components. c. Oscillation in 6626/OA2-WA tube.	a. Locate and replace defective tube. b. Locate and replace defective components. c. Replace 6626/OA2WA tube.
10. Maximum calibrate level less than 20 lines.	a. Weak 12AX7, 12AT7WA, 5687, 6BW4, or 6080 tube. b. Dirty calibrate cell contacts. c. Inoperative calibrate cell.	a. Locate and replace defective tube. b. Clean calibrate cell contacts. c. Replace calibrate cell.
11. Incorrect values for VOLTS/CHART LINE switch steps.	a. Changed resistance value in attenuator resistors. b. Grounded components in attenuator assembly.	a. Locate and replace defective resistors. b. Locate and eliminate grounds.
12. Amplifier cannot be frequency compensated.	a. Improper frequency compensation procedure. b. Defective dual potentiometer, switch, or capacitor in compensation network.	a. Refer to Operating Instructions for proper procedure. b. Locate and replace defective components.
13. Poor d.c. linearity.	a. Weak tube in d.c. amplifier section. b. Defective penmotor.	a. Locate and replace defective tube. b. Replace penmotor or oscillograph.
CARRIER AMPLIFIER SECTION		
1. D.C. Amplifier section operates normally. Output indicated on oscillograph chart (without input to amplifier) when the VOLTS/CHART LINE switch is turned to the "carrier" position, INPUT switch is in "grounded" position, CHART MULTIPLIER switch is in "off" position, CARRIER GAIN control is fully clockwise, and the SELECTOR switch is in the "in phase" position.	a. DETECTOR BALANCE control improperly adjusted. b. Inoperative 6AL5 tube. c. Defective 12AX7, 12AU7, or 12AT7WA tube. d. Defective components in detector or amplifier circuits.	a. Refer to the Operating Instructions for proper adjustment procedure. b. Replace defective tube. c. Replace defective tube. d. Locate and replace defective components.

SYMPTOM	CAUSE	REMEDY
2. Amplifier operates, but shows low sensitivity in "carrier" operation.	a. Inadequate voltage output to bridge or LVDT transducer.	a. Adjust the OSCILLATOR AMPLITUDE control to obtain proper carrier level. If the adjustment above does not correct the low sensitivity condition, replace the 12AU7 (oscillator) tube. Locate and eliminate shorts in sync cables which would interfere with oscillator operation.
	b. Weak tube in carrier amplifier section.	b. Locate and replace defective tube.
	c. CALIBRATION RESISTOR value incorrect for Strain gage resistance used.	c. Check specifications for proper value of CALIBRATION RESISTOR.
3. Oscillograph chart indicates non-linearity in "carrier" operation.	a. Bridge circuit not properly balanced.	a. Balance the system as described in Operating Instructions.
	b. DETECTOR BALANCE control not properly adjusted.	b. Refer to Operating Instructions for proper adjustment procedure.
	c. Defective diode in 6AL5 tube.	c. Replace defective tube.
	d. Carrier detector level not adjusted properly.	d. Adjust carrier detector level as specified for the transducer being used.
	e. Weak 12AX7, 12AU7, or 12AT7WA tube.	e. Locate and replace defective tubes.
4. Beat note appears on chart when the amplifier is used in multi-channel operation.	a. No sync connection between oscillators.	a. Interconnect all active oscillators through SYNC connectors.
	b. One amplifier turned off while still connected in system "sync" circuit.	b. Turn on all amplifiers or disconnect sync cable from unused amplifier.
5. Incorrect values for CHART MULTIPLIER steps.	a. Changed resistance value for resistors in switch assembly.	a. Locate and replace defective resistors.
	b. Grounded resistor or contact on CHART MULTIPLIER switch assembly.	b. Locate and eliminate grounds.
POWER SUPPLY		
1. +B to —B regulated voltage varies, or is erratic.	a. Insufficient line voltage.	a. Connect amplifier to proper power source.
	b. Defective 6BW4, 6080, 5751, or 6626/OA2WA tube.	b. Locate and replace defective tubes.
	c. Inoperative filter capacitors.	c. Locate and replace defective filter capacitors.
	d. Defective components in power supply.	d. Locate and replace defective components.

PARTS IDENTIFICATION

Components of the Universal Amplifier may be identified by means of Figures 30 through 40 (below). The symbols appearing on these illustrations are correlated with the Parts List and the Schematic Diagram. In addition to identification of parts, Figure 37 includes a color code for connection of wiring to the printed wiring board in the medium gain d.c. amplifier section.

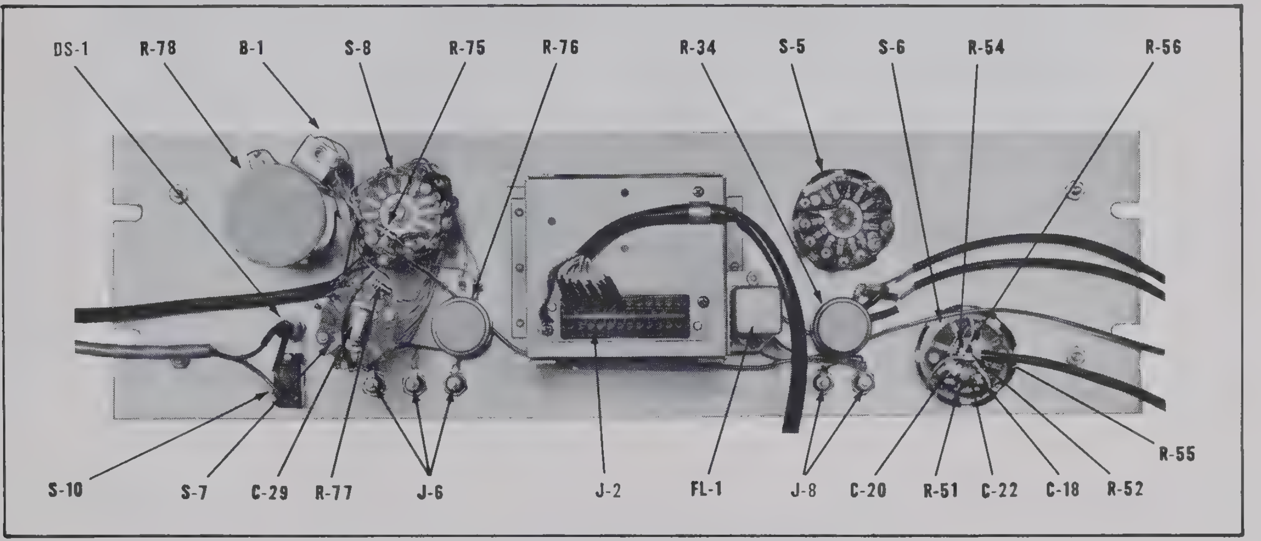


Fig. 30. Rear View—Front Panel Assembly.

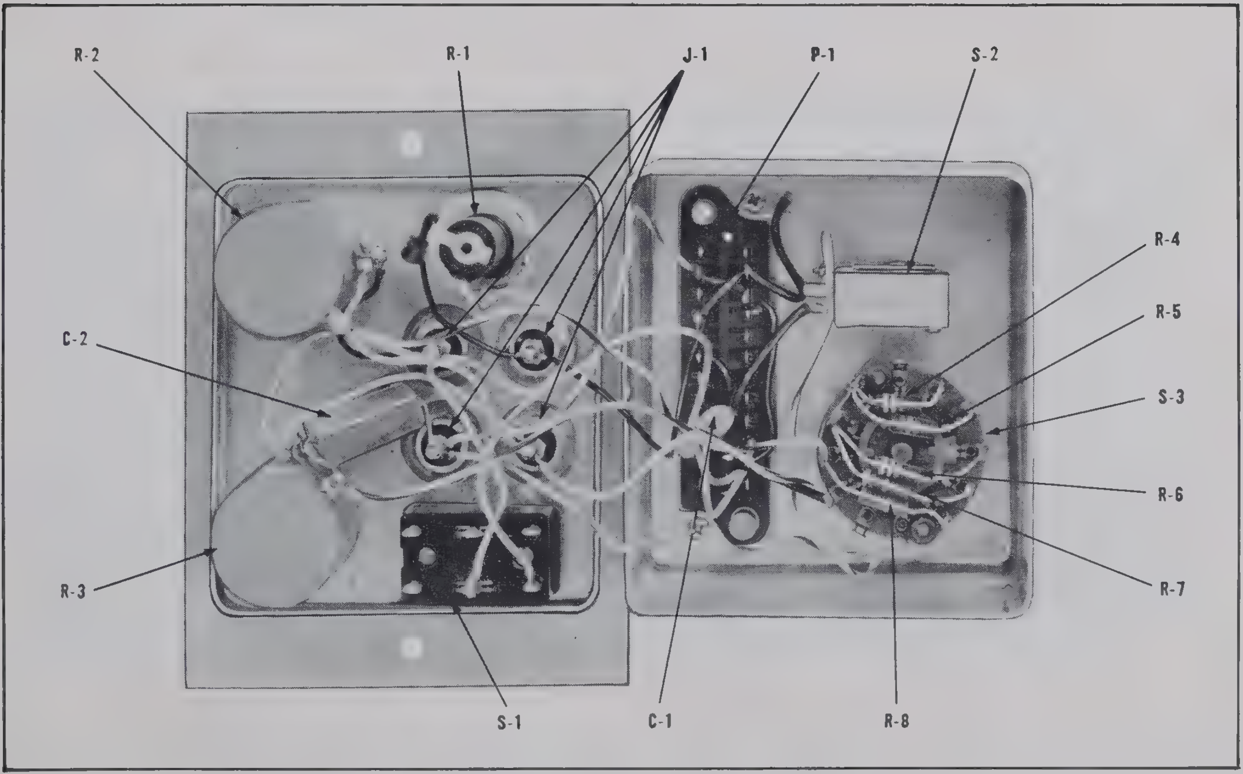


Fig. 31. Internal View—Bridge Balance Model RA 5212 00.

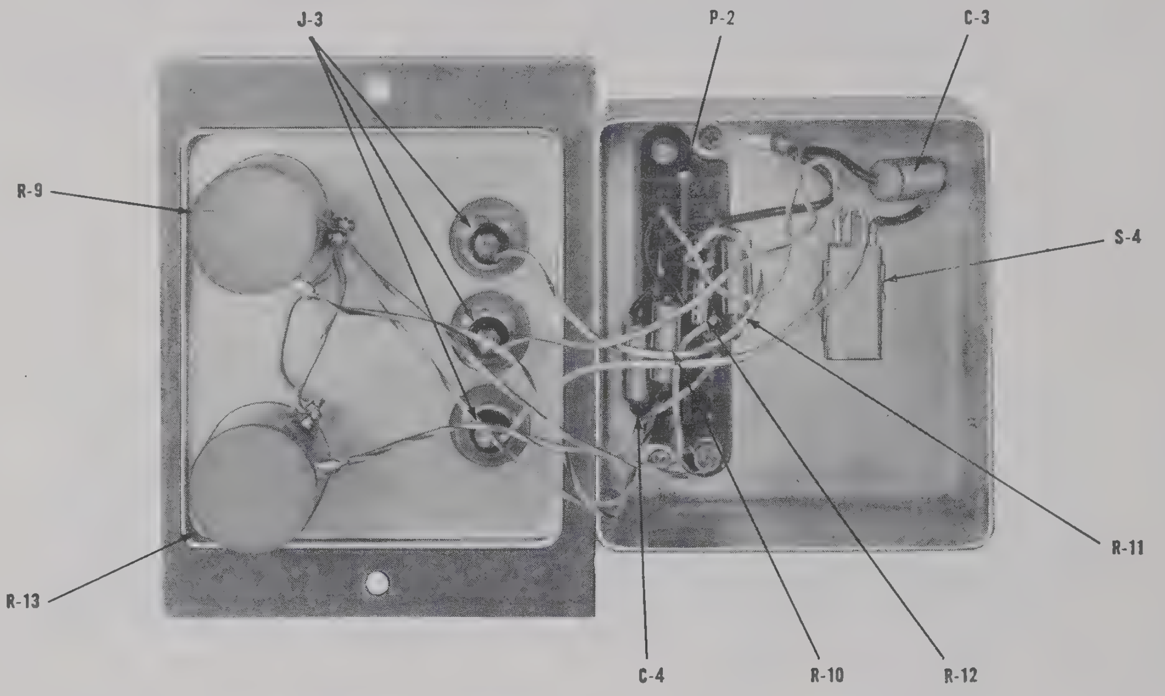


Fig. 32. Internal View—LVDT Balance Model RA 5222 00.

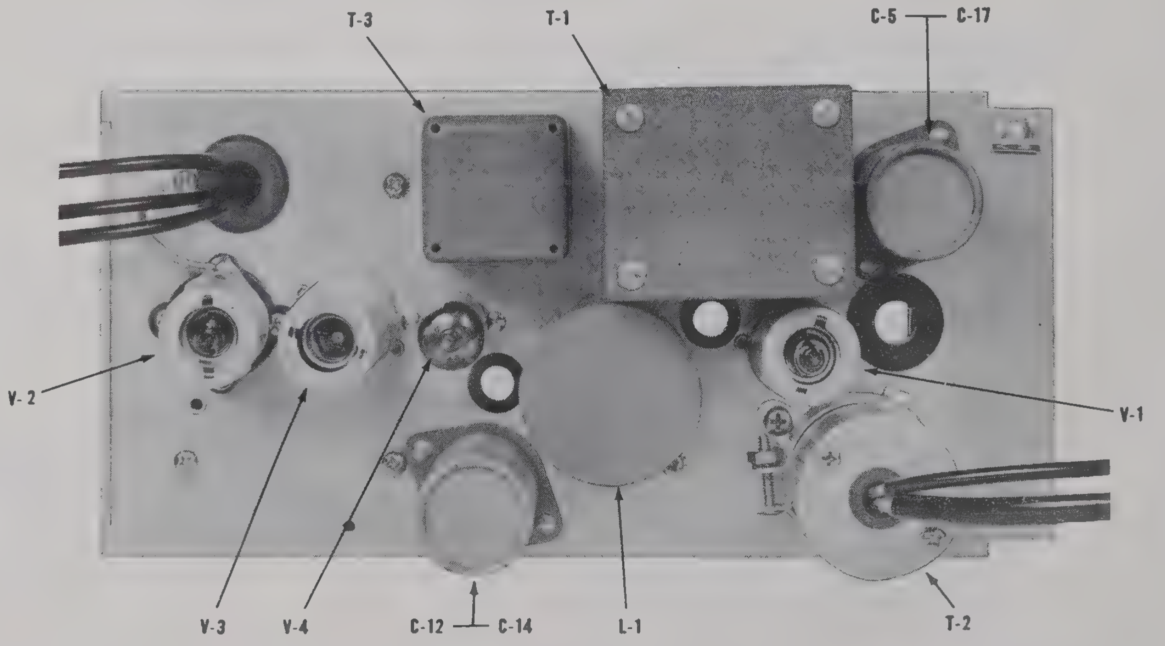


Fig. 33. Inside View—Left Side Chassis.

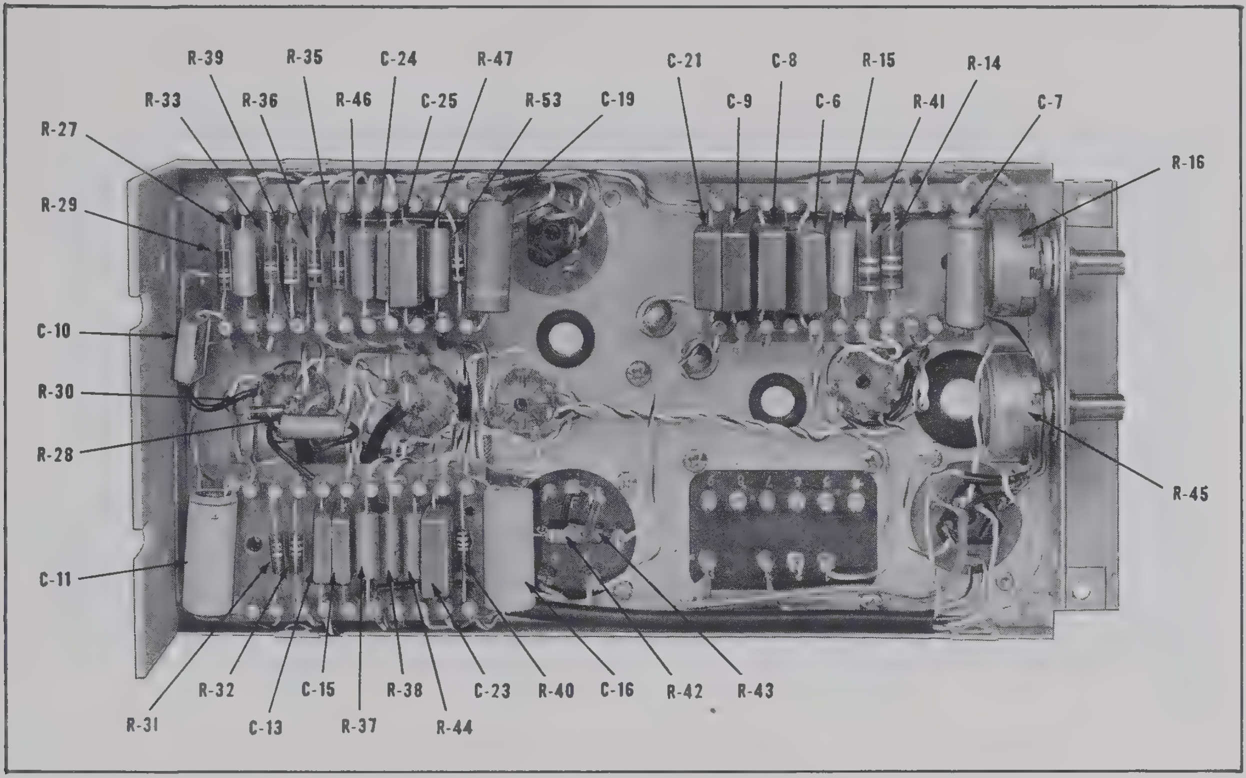


Fig. 34. Outside View—Left Side Chassis.

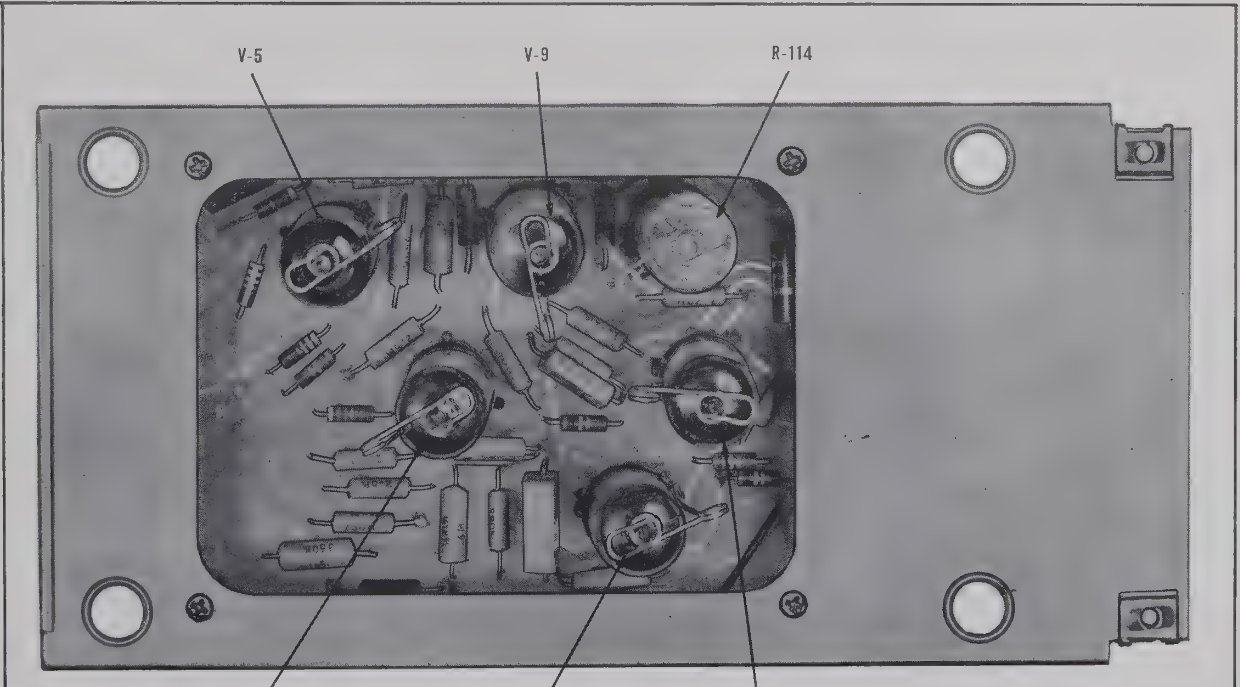


Fig. 35. Inside View – Right Side Chassis.

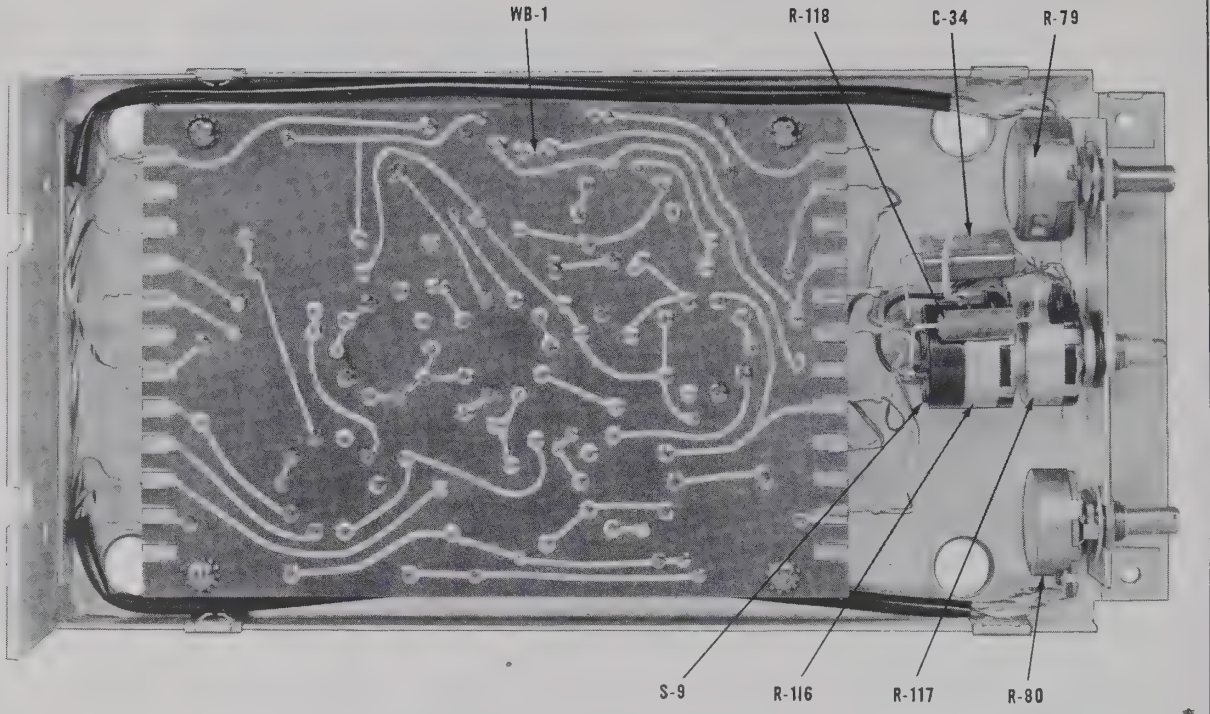


Fig. 36. Outside View—Right Side Chassis.

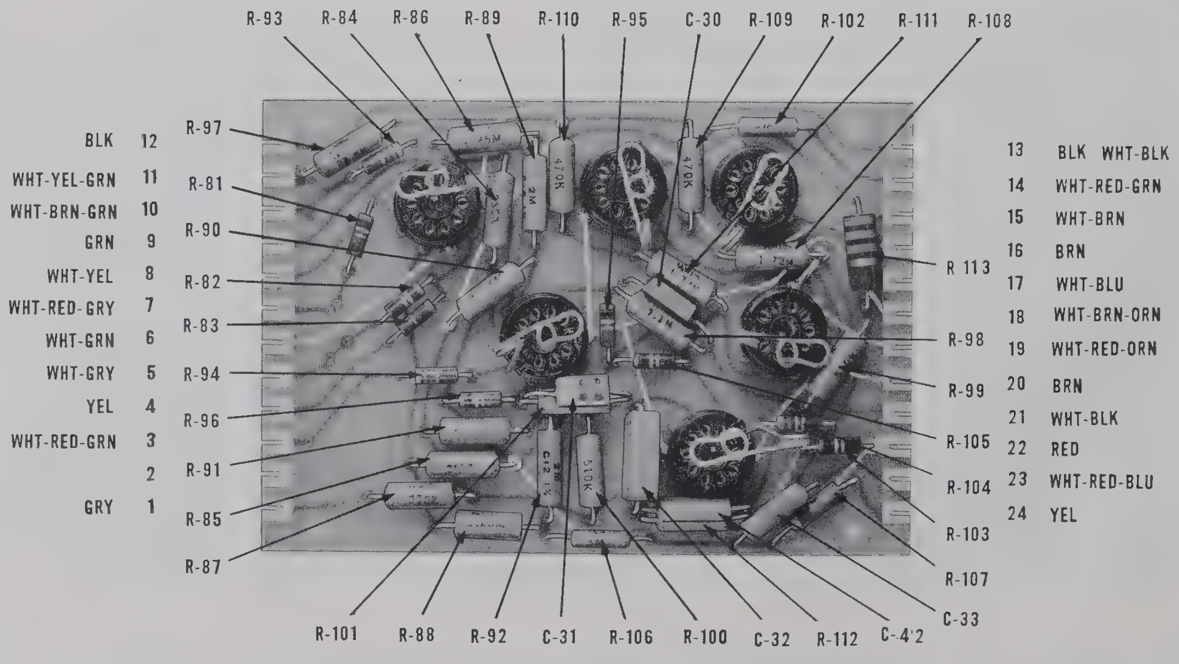


Fig. 37. Printed Wiring Board (Less Tubes).

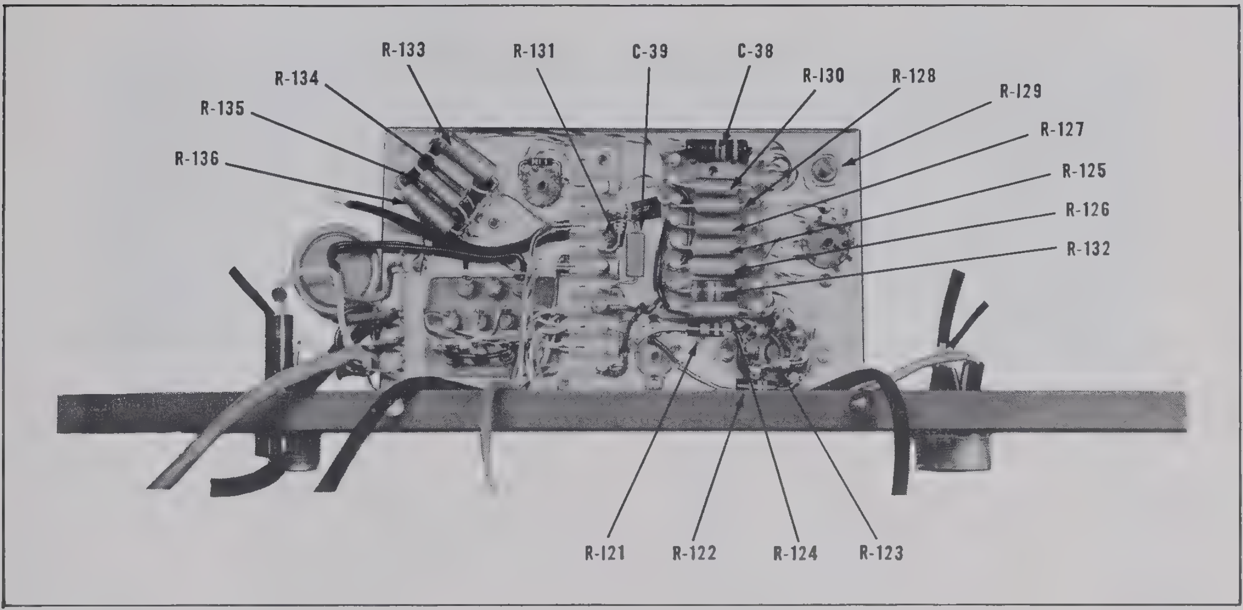


Fig. 38. Top View—Power Supply.

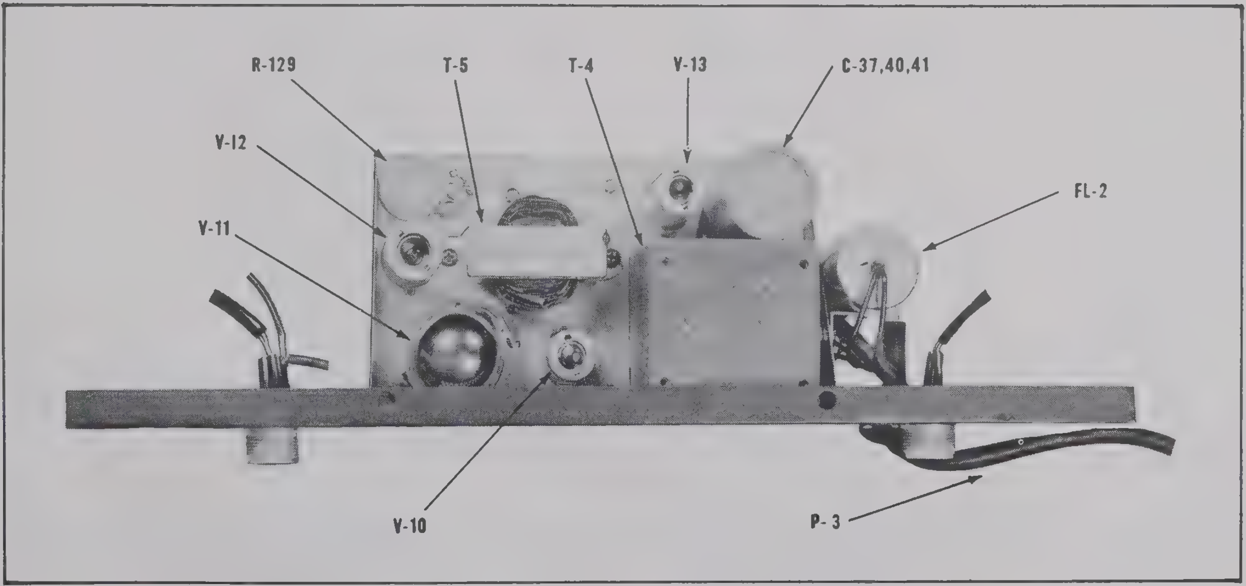


Fig. 39. Bottom View—Power Supply.

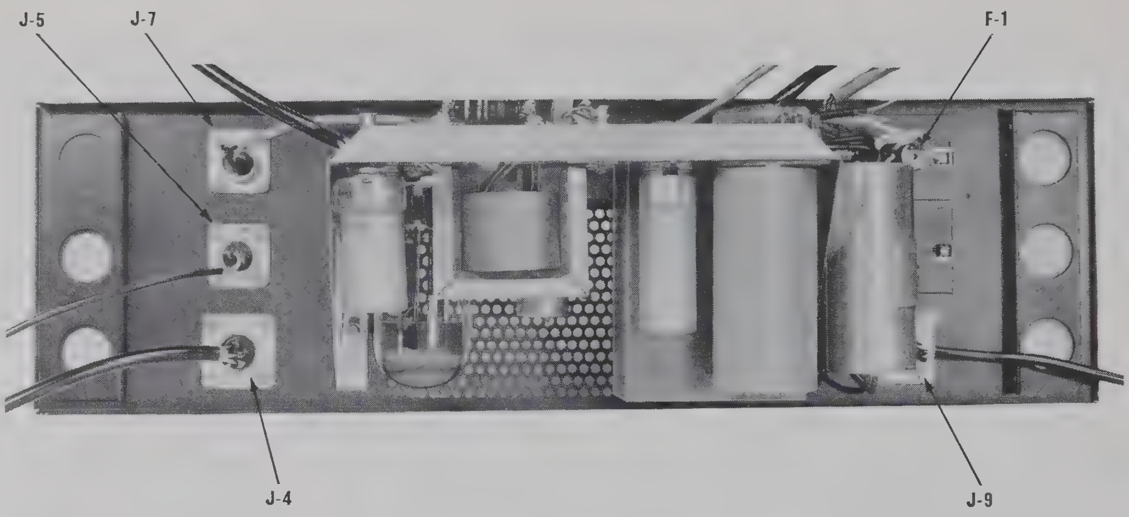


Fig. 40. Inside View--Rear Panel Assembly.

PARTS LIST

In order to assure prompt and satisfactory delivery of replacement parts, it is very necessary that you include the following information with your order:

1. The name and serial number of the instrument for which the parts are to be used. For example, "Universal Amplifier Model RD 5612 00 Serial No. 123".
2. Specific information on desired parts, from the PARTS LIST, as published in the Operating Instructions:
   Description
   Value (Electrical)
   Brush Part No.

NOTE: Do not use the SYMBOL No. for identifying desired parts on your order.

SYMBOL	DESCRIPTION	VALUE	BRUSH PART NO.
B-1	Cell, Mercury	2.5V	126377-4
C-1	Capacitor, Ceramic	.0039 mfd, ± 20%, 500V	20-118102-392
C-2	Capacitor, Mica	.0015 mfd, ± 10%, 500V	10-117265-152
C-3	Capacitor, Paper	0.1 mfd, ± 10%, 200V	10-120554-104
C-4	Capacitor, Mica	330 mmfd, ± 10%, 500V	10-117264-331
C-5	Capacitor, Electrolytic (½ Dual Section)	10 mfd, 450V	117717-106
C-6	Capacitor, Mica	.0056 mfd, ± 5%, 500V	5-122233-562
C-7	Capacitor, Paper	.02 mfd, ±10%, 200V	10-217608-203
C-8	Capacitor, Mica	.01 mfd, ± 5%, 500V	5-122233-103
C-9	Capacitor, Mica	.01 mfd, ± 5%, 500V	5-122233-103
C-10	Capacitor, Mica	.001 mfd, ± 10%, 500V	10-117265-102
C-11	Capacitor, Electrolytic	10 mfd, 25V	100-117680-106
C-12	Capacitor, Electrolytic (½ Dual Section)	10 mfd, 450V	117717-106
C-13	Capacitor, Mica	470 mmfd, ± 10%, 500V	10-117264-471
C-14	Capacitor, Electrolytic (½ Dual Section)	10 mfd, 450V	(Part of C-12)
C-15	Capacitor, Mica	470 mmfd, ± 10%, 500V	10-117264-471
C-16	Capacitor, Electrolytic	10 mfd, 25V	100-117680-106
C-17	Capacitor, Electrolytic (½ Dual Section)	10 mfd, 450V	(Part of C-5)
C-18	Capacitor, Ceramic	.01 mfd, 500V	1-117964-103
C-19	Capacitor, Paper	.5 mfd, ±20%, 200V	20-120554-504
C-20	Capacitor, Ceramic	.002 mfd, 500V	1-117964-202
C-21	Capacitor, Mica	.0033 mfd, ± 10%, 500V	10-117265-332
C-22	Capacitor, Ceramic	510 mmfd, ± 20%, 500V	20-118102-511
C-23	Capacitor, Mica	.001 mfd, ± 10%, 500V	10-117264-102
C-24	Capacitor, Mica	.001 mfd, ± 10%, 500V	10-117264-102
C-25	Capacitor, Mica	270 mmfd, ± 5%, 500V	5-119621-271
C-26	Capacitor, Mica	.0015 mfd, ± 10%, 500V	10-117265-152
C-27	Capacitor, Mica	510 mmfd, ± 5%, 500V	5-117264-511
C-28	Capacitor, Mica	270 mmfd, ± 5%, 500V	5-119621-271
C-29	Capacitor, Paper	.05 mfd, ± 10%, 400V	10-120555-503
C-30	Capacitor, Mica	68 mmfd, ± 5%, 500V	5-117264-680
C-31	Capacitor, Mica	68 mmfd, ± 5%, 500V	5-117264-680
C-32	Capacitor, Mica	.0033 mfd, ± 5%, 500V	5-117265-332
C-33	Capacitor, Mica	.001 mfd, ± 5%, 500V	5-117264-102
C-34	Capacitor, Mica	.0024 mfd, ± 5%, 500V	5-122233-242

PARTS LIST (Cont'd)

SYMBOL	DESCRIPTION	VALUE	BRUSH PART NO.
~~C-35~~	~~Capacitor, Paper~~	~~.25 mfd, ± 10%, 200V~~	~~10-120554-254~~
~~C-36~~	~~Capacitor, Paper~~	~~.25 mfd, ± 10%, 200V~~	~~10-120554-254~~
C-37	Capacitor, Electrolytic (⅓ Triple Section)	20 mfd, 450V	117718-206
C-38	Capacitor, Paper	.01 mfd, ± 10%, 400V	10-217413-103
C-39	Capacitor, Mica	.0022 mfd, ± 10%, 500V	10-117265-222
C-40	Capacitor, Electrolytic (⅓ Triple Section)	20 mfd, 450V	(Part of C-37)
C-41	Capacitor, Electrolytic (⅓ Triple Section)	20 mfd, 450V	(Part of C-37)
C-42	Capacitor, Mica	470 mmfd, ± 5%, 500V	5-117264-471
F-1	Fuse	2 Amp, 250V, Type 3AG	102625
FL-1	Filter Assembly		326581-910
FL-2	Filter, Power Line	3 Amp, 110-220V	123361
J-1	Connector, Receptacle, Binding Post (4)	GR Type	126395-3
J-2	Connector, Receptacle, Male	Strip Type	118040-24
J-3	Connector, Receptacle, Binding Post (3)	GR Type	126395-3
J-4	Connector, Receptacle, Female, 5 Pin	AN Type—AN 3102A-14S-5S	119989
	Connector, Plug, Male, 5 Pin	AN Type—AN 3106A-14S-5P	119973
	Cable Clamp		119993-106
J-5	Connector, Receptacle, Male, 2 Pin	AN Type—AN 3102A-10SL-4P	119972
	Connector, Plug, Female, 2 Pin	AN Type—AN 3106A-10SL-4S	119992
	Cable Clamp		119993-104
J-6	Connector, Binding Post (3)	GR Type	126395-3
J-7	Connector, Receptacle, Male, 3 Pin	AN Type—AN 3102A-10SL-3P	121274
	Connector, Plug, Female, 3 Pin	AN Type—AN 3106B-10SL-3S	121275
	Cable Clamp		119993-104
J-8	Connector, Binding Post (2)	GR Type	126395-3
J-9	Connector, Receptacle, Female, 6 Pin	AN Type—AN 3102A-14S-6S	119990
	Amplifier to Oscillograph Signal Cable		223385-501
L-1	Coil, Oscillator	1250 mhy	106588-2
P-1	Connector, Plug, Female	Strip Type	118041-24
P-2	Connector, Plug, Female	Strip Type	118041-24
P-3	Plug, Power, With Cord	2 Conductor	126551-6
PS-1	Lamp, Neon (Red)		126621
R-1	Resistor, Precision (Calibration)	390K, ± 1%, ½W	109577-3903
R-2	Resistor, Variable, 10 Turn	2K, 1½W	119048
R-3	Resistor, Variable, 10 Turn	2K, 1½W	119048
R-4	Resistor, Composition	240K, ± 5%, ½W	5-115557-244
R-5	Resistor, Composition	56K, ± 5%, ½W	5-115557-563
R-6	Resistor, Composition	24K, ± 5%, ½W	5-115557-243
R-7	Resistor, Composition	4.7K, ± 5%, ½W	5-115557-472
R-8	Resistor, Composition	1.5K, ± 5%, ½W	5-115557-152
R-9	Resistor, Variable, 10 Turn	2K, 1½W	119048
R-10	Resistor, Precision	150K, ± 1%, ½W	1-117802-1503
R-11	Resistor, Precision	220 ohms, ± 1%, ½W	1-117802-2200
R-12	Resistor, Composition	20 ohms, ± 5%, ½W	5-115557-200
R-13	Resistor, Variable, 10 Turn	2K, 1½W	119048
R-14	Resistor, Composition	10K, ± 5%, 1W	5-115558-103
R-15	Resistor, Precision	150K, ± 1%, ½W	1-117802-1503
R-16	Resistor, Variable	100K	19-211473-104
R-17	Resistor, Precision	245K, ± 1%, ½W	1-117802-2453
R-18	Resistor, Precision	154K, ± 1%, ½W	1-117802-1543
R-19	Resistor, Precision	51.0K, ± 1%, ½W	1-117802-5102
R-20	Resistor, Precision	25.0K, ± 1%, ½W	1-117802-2502
R-21	Resistor, Precision	15.0K, ± 1%, ½W	1-117802-1502
R-22	Resistor, Precision	5.00K, ± 1%, ½W	1-117802-5001
R-23	Resistor, Precision	2.50K, ± 1%, ½W	1-117802-2501
R-24	Resistor, Precision	1.50K, ± 1%, ½W	1-117802-1501
R-25	Resistor, Precision	500 ohms, ± 1%, ½W	1-117802-5000
R-26	Resistor, Precision	500 ohms, ± 1%, ½W	1-117802-5000

PARTS LIST (Cont'd)

SYMBOL	DESCRIPTION	VALUE	BRUSH PART NO.
R-27	Resistor, Precision	4.7K, ± 1%, ½W	1-117802-4701
R-28	Resistor, Precision	1.0M, ± 1%, ½W	1-117802-1004
R-29	Resistor, Composition	270K, ± 5%, ½W	5-115557-274
R-30	Resistor, Composition	1.0M, ± 5%, ½W	5-115557-105
R-31	Resistor, Composition	8.2K, ± 5% ½W	5-115557-822
R-32	Resistor, Composition	270K, ± 5%, ½W	5-115557-274
R-33	Resistor, Composition	82K, ± 5%, ½W	5-115557-823
R-34	Resistor, Variable	1.0M	10-212023-105
R-35	Resistor, Composition	1.0K, ± 5%, ½W	5-115557-102
R-36	Resistor, Composition	100K, ± 5%, ½W	5-115557-104
R-37	Resistor, Composition	1.0M, ± 5%, ½W	5-115557-105
R-38	Resistor, Precision	117K, ± 1%, ½W	1-117802-1173
R-39	Resistor, Composition	47K, ± 5%, ½W	5-115557-473
R-40	Resistor, Composition	680 ohms, ± 5%, ½W	5-115557-681
R-41	Resistor, Composition	10K, ± 5%, 1W	5-115558-103
R-42	Resistor, Composition	22K, ± 5%, ½W	5-115557-223
R-43	Resistor, Composition	22K, ± 5%, ½W	5-115557-223
R-44	Resistor, Precision	1.0M, ± 1%, ½W	1-117802-1004
R-45	Resistor, Variable	250K	19-211473-254
R-46	Resistor, Precision	1.0M, ± 1%, ½W	1-117802-1004
R-47	Resistor, Precision	1.0M, ± 1%, ½W	1-117802-1004
R-48	Resistor, Precision	330K, ± 1%, ½W	1-117802-3303
R-49	Resistor, Precision	330K, ± 1%, ½W	1-117802-3303
R-50	Resistor, Precision	165K, ± 1%, ½W	1-117802-1653
R-51	Resistor, Composition	220K, ± 5%, ½W	5-115557-224
R-52	Resistor, Composition	100K, ± 5%, ½W	5-115557-104
R-53	Resistor, Composition	10K, ± 5%, ½W	5-115557-103
R-54	Resistor, Composition	27K, ± 5%, ½W	5-115557-273
R-55	Resistor, Composition	270K, ± 5%, ½W	5-115557-274
R-56	Resistor, Composition	100K, ± 5%, ½W	5-115557-104
R-57	Resistor, Precision	2.50M, ± 0.5%, ½W	50-117802-2504
R-58	Resistor, Precision	1.25M, ± 0.5%, ½W	50-117802-1254
R-59	Resistor, Precision	750K, ± 0.5%, ½W	50-117802-7503
R-60	Resistor, Precision	250K, ± 0.5%, ½W	50-117802-2503
R-61	Resistor, Precision	125K, ± 0.5%, ½W	50-117802-1253
R-62	Resistor, Precision	75.0K, ± 0.5%, ½W	50-117802-7502
R-63	Resistor, Precision	25.0K, ± 0.5%, ½W	50-117802-2502
R-64	Resistor, Precision	25.0K, ± 0.5%, ½W	50-117802-2502
R-65	Resistor, Precision	.95M, ± 1%, ½W	1-117802-9503
R-66	Resistor, Precision	.56M, ± 1%, ½W	1-117802-5603
R-67	Resistor, Precision	2.50M, ± 0.5%, ½W	50-117802-2504
R-68	Resistor, Precision	1.25M, ± 0.5%, ½W	50-117802-1254
R-69	Resistor, Precision	750K ± 0.5%, ½W	50-117802-7503
R-70	Resistor, Precision	250K, ± 0.5%, ½W	50-117802-2503
R-71	Resistor, Precision	125K, ± 0.5%, ½W	50-117802-1253
R-72	Resistor, Precision	75.0K, ± 0.5%, ½W	50-117802-7502
R-73	Resistor, Precision	25.0K, ± 0.5% ½W	50-117802-2502
R-74	Resistor, Precision	25.0K, ± 0.5%, ½W	50-117802-2502
R-75	Resistor, Composition	15K, ± 5%, ½W	5-115557-153
R-76	Resistor, Variable	1.0M	2-212022-105
R-77	Resistor, Composition	470K, ± 5%, ½W	5-115557-474
R-78	Resistor, Variable, 10 Turn	50K, 4W	5-117686-503
R-79	Resistor, Variable	10K	19-211473-103
R-80	Resistor, Variable	3K, ± 20%, ½W	20-125156-302
R-81	Resistor, Composition	33K, ± 5%, ½W	5-115557-333

PARTS LIST (Cont'd)

SYMBOL	DESCRIPTION	VALUE	BRUSH PART NO.
R-82	Resistor, Composition	33K, ± 5%, ½W	5-115557-333
R-83	Resistor, Composition	12K, ± 5%, ½W	5-115557-123
R-84	Resistor, Precision	250K, ± 1%, ½W	1-117802-2503
R-85	Resistor, Precision	250K, ± 1%, ½W	1-117802-2503
R-86	Resistor, Precision	2.50M, ± 1%, ½W	1-117802-2504
R-87	Resistor, Precision	350K, ± 1%, ½W	1-117802-3503
R-88	Resistor, Precision	2.50M, ± 1%, ½W	1-117802-2504
R-89	Resistor, Precision	4.00M, ± 1%, ½W	1-117802-4004
R-90	Resistor, Precision	2.50M, ± 1%, ½W	1-117802-2504
R-91	Resistor, Precision	2.50M, ± 1%, ½W	1-117802-2504
R-92	Resistor, Precision	4.00M, ± 1%, ½W	1-117802-4004
R-93	Resistor, Composition	3.6K, ± 5%, ½W	5-115557-362
R-94	Resistor, Composition	3.6K, ± 5%, ½W	5-115557-362
R-95	Resistor, Composition	100K, ± 5%, ½W	5-115557-104
R-96	Resistor, Composition	100K, ± 5%, ½W	5-115557-104
R-97	Resistor, Precision	39.0K, ± 1%, ½W	1-117802-3902
R-98	Resistor, Precision	1.10M, ± 1%, ½W	1-117802-1104
R-99	Resistor, Precision	390K, ± 1%, ½W	1-117802-3903
R-100	Resistor, Precision	390K, ± 1%, ½W	1-117802-3903
R-101	Resistor, Precision	1.10M, ± 1%, ½W	1-117802-1104
R-102	Resistor, Precision	3.30M, ± 1%, ½W	1-117802-3304
R-103	Resistor, Composition	100K, ± 5%, ½W	5-115557-104
R-104	Resistor, Precision	27.0K, ± 1%, ½W	1-117802-2702
R-105	Resistor, Composition	100K, ± 5%, ½W	5-115557-104
R-106	Resistor, Precision	3.30M, ± 1%, ½W	1-117802-3304
R-107	Resistor, Precision	1.00M, ± 1%, ½W	1-117802-1004
R-108	Resistor, Precision	1.72M, ± 1%, ½W	1-117802-1724
R-109	Resistor, Precision	470K, ± 1%, ½W	1-117802-4703
R-110	Resistor, Precision	470K, ± 1%, ½W	1-117802-4703
R-111	Resistor, Precision	1.72M, ± 1%, ½W	1-117802-1724
R-112	**Resistor, Precision**	**470K, ± 1%, ½W**	**1-117802-4703**
R-113	**Resistor, Composition**	**1.1K, ± 5%, 2W**	**5-115559-112**
R-114	**Resistor, Ballast**		**119373**
R-116	**Resistor, Variable (½ Dual Section)**	**1.0M, ± 5%, ½W**	**126255**
R-117	Resistor, Variable (½ Dual Section)	1.0M, ± 5%, ½W	(Part of R-116)
R-118	Resistor, Precision	1.00M, ± 1%, ½W	1-117802-1004
~~R-119~~	~~Resistor, Composition~~	~~330K, ± 5%, ½W~~	~~5-115557-334~~
~~R-120~~	~~Resistor, Composition~~	~~220K, ± 5%, ½W~~	~~5-115557-224~~
R-121	Resistor, Composition	68 ohms, ± 5%, 1W	5-115558-680
R-122	Resistor, Composition	68 ohms, ± 5%, 1W	5-115558-680
R-123	Resistor, Composition	100 ohms, ± 5%, ½W	5-115557-101
R-124	Resistor, Precision	1.00M, ± 1%, ½W	1-117802-1004
R-125	Resistor, Precision	5.00M, ± 1%, ½W	1-117802-5004
R-126	Resistor, Precision	5.00M, ± 1%, ½W	1-117802-5004
R-127	Resistor, Precision	1.00M, ± 1%, ½W	1-117802-1004
R-128	Resistor, Precision	350K, ± 1%, ½W	1-117802-3503
R-129	Resistor, Variable	100K	19-211473-104
R-130	Resistor, Precision	150K, ± 1%, ½W	1-117802-1503
R-131	Resistor, Composition	220K, ± 5%, ½W	5-115557-224
R-132	Resistor, Composition	10K, ± 5%, 2W	5-115559-103
R-133	Resistor, Precision	27.0K, ± 1%, 1W	1-117803-2702
R-134	Resistor, Precision	2.20K, ± 1%, ½W	1-117802-2201
R-135	Resistor, Precision	2.20K, ± 1%, ½W	1-117802-2201

PARTS LIST (Cont'd)

SYMBOL	DESCRIPTION	VALUE	BRUSH PART NO.
R-136	Resistor, Precision	18.0K, ± 1%, 1W	1-117803-1802
R-137	Resistor, Wire Wound	120 ohms, ± ¼%, 1W	3-108688-102
R-138	Resistor, Wire Wound	120 ohms, ± ¼%, 1W	3-108688-102
R-139	Resistor, Wire Wound	120 ohms, ± ¼%, 1W	3-108688-102
R-140	Resistor, Wire Wound	120 ohms, ± ¼%, 1W	3-108688-102
S-1	Switch, Toggle, D.P.D.T., Momentary Contact		124334
S-2	Switch, Toggle, S.P.S.T.		1-103258-201
S-3	Switch, Rotary		127540
S-4	Switch, Toggle, S.P.S.T.		1-103258-201
S-5	Switch, Rotary		226513
S-6	Switch, Rotary		126453
S-7	Switch, Rotary		226394
S-8	Switch, Rotary		226427
S-9	Switch, D.P.S.T.		(Part of R-116)
S-10	Switch, Toggle, S.P.S.T.		121068
T-1	Transformer		120141
T-2	Transformer		106602-1
T-3	Transformer		118535
T-4	Transformer		121553
T-5	Transformer		118920
V-1	Tube, Electron, 12AU7		125834
V-2	Tube, Electron, 12AX7		125835
V-3	Tube, Electron, 12AT7WA		125833
V-4	Tube, Electron, 6AL5		109996
V-5	Tube, Electron, 12AX7		125835
V-6	Tube, Electron, 12AT7WA		125833
V-7	Tube, Electron, 12AT7WA		125833
V-8	Tube, Electron, 5687		122828
V-9	Tube, Electron, 5687		122828
V-10	Tube, Electron, 6BW4		126997
V-11	Tube, Electron, 6080		115687
V-12	Tube, Electron, 5751		119028
V-13	Tube, Electron, 6626/OA2WA		127658
WB-1	Board, Printed Wiring (Less Tubes)		326545-910

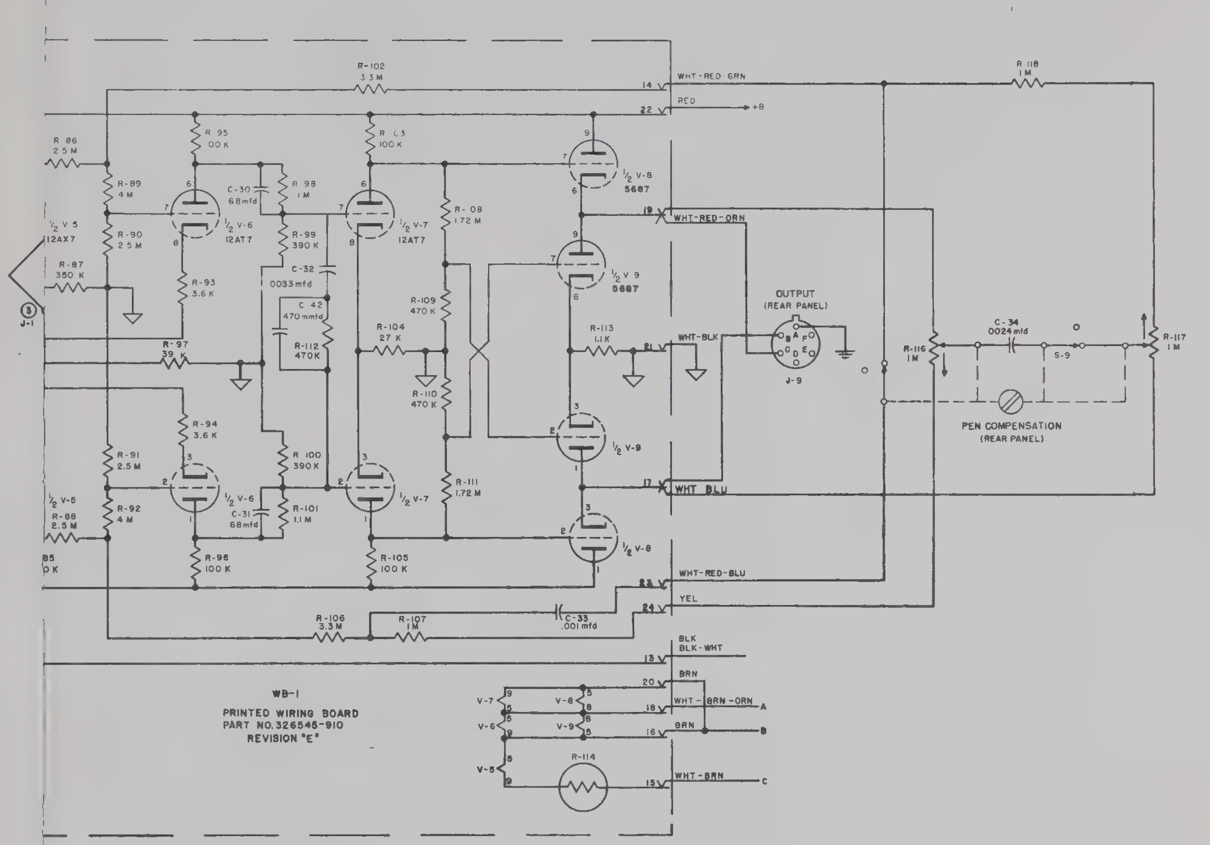
TUBE SOCKET PIN VOLTAGES

1. Voltages should be measured under the following conditions:
   a. VOLTS/CHART LINE switch set in the "off" position.
   b. CALIBRATION control fully counterclockwise.
   c. A 1500 ohm resistor connected across the output terminals (pins "B" and "C" of the output connector).
   d. Voltage across the output resistor adjusted to zero (0 volts) by means of the PEN BIAS control.
   e. CHART MULTIPLIER switch set in the "off" position.
   f. CARRIER GAIN control fully counterclockwise.
   g. SELECTOR switch in the "balance" position.
2. All d.c. measurements should be made with a d.c. voltmeter with a minimum of ten (10) megohms input impedance.
3. All a.c. voltages should be measured with an accurate RMS a.c. voltmeter (20,000 ohms per volt or higher).
4. The +B voltage should be adjusted to 235 volts as described in the Operating Instructions under "Tube Replacement" (Section V—Maintenance).
5. All measurements should be made from the tube pin to —B (⏚) point, except where otherwise noted.
6. Variations in observed voltage readings from tabulated values do not necessarily indicate improper operation unless deviations exceed 10%.

TUBE No.	TYPE	PIN NUMBER								
		1	2	3	4	5	6	7	8	9
V-1	12AU7	170	0	7	Note 1		170	0	7	—
V-2	12AX7	90	0	1.0	Note 1		79	0	1.0	—
V-3	12AT7WA	107	0	2.0	Note 1		174	0	2.0	—
V-4	6AL5	97	97	Note 2		120	—	74	—	—
V-5	12AX7	197	97	98	Note 1		197	97	98	—
V-6	12AT7WA	155	56	57	Note 1		155	56	57	—
V-7	12AT7WA	152	41	42	Note 1		152	41	42	—
V-8	5687	235	150	154	Note 3		154	150	—	235
V-9	5687	153	33	37	Note 3		137	33	—	153
V-10	6BW4	—	305	Note 2		—	—	305	—	—
V-11	6080	200	302	235	200	302	235	Note 4		—
V-12	5751	200	87	86	Note 1		182	87	86	—
V-13	6626/ OA2WA	—	87	—	—	235	—	—	—	—

NOTES:

1. 6.3 volts a.c. measured from pins 4 and 5 to pin 9.
2. 6.3 volts a.c. measured from pin 3 to pin 4.
3. 6.3 volts a.c. measured from pins 4 and 5 to pin 8.
4. 6.3 volts a.c. measured from pin 7 to pin 8.



▽ -B CONNECTIONS
⏚ CHASSIS GROUND CONNECTIONS
↑ INDICATES CLOCKWISE ROTATION
⊘ INDICATES SCREWDRIVER CONTROL

TUBE SOCKET PIN VOLTAGES

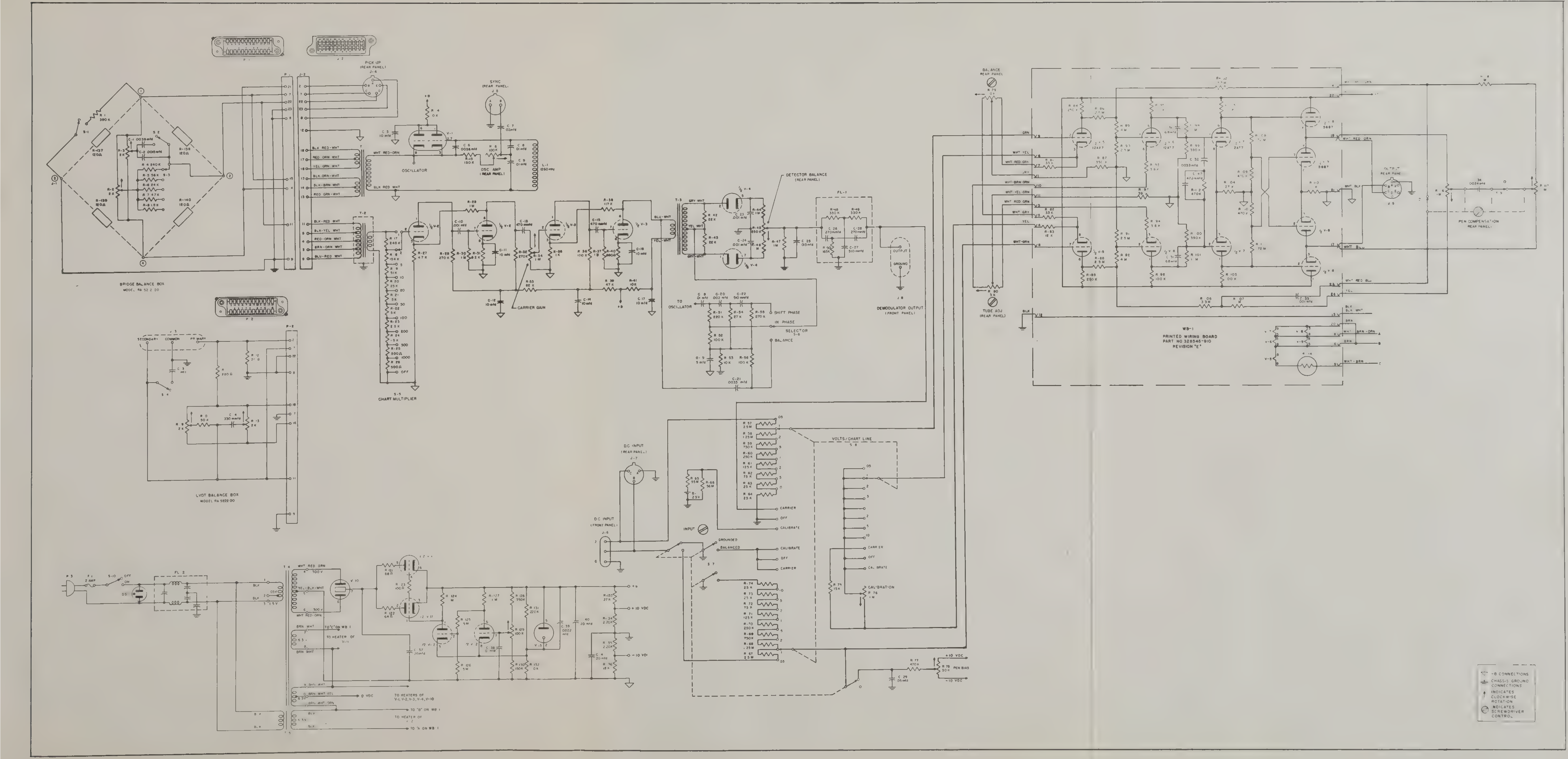
1. Voltages should be measured under the following conditions:
    - a. VOLTS/CHART LINE switch set in the "off" position.
    - b. CALIBRATION control fully counterclockwise.
    - c. A 1500 ohm resistor connected across the output terminals (pins "B" and "C" of the output connector).
    - d. Voltage across the output resistor adjusted to zero (0 volts) by means of the PEN BIAS control.
    - e. CHART MULTIPLIER switch set in the "off" position.
    - f. CARRIER GAIN control fully counterclockwise.
    - g. SELECTOR switch in the "balance" position.
2. All d.c. measurements should be made with a d.c. voltmeter with a minimum of ten (10) megohms input impedance.
3. All a.c. voltages should be measured with an accurate RMS a.c. voltmeter (20,000 ohms per volt or higher).
4. The +B voltage should be adjusted to 235 volts as described in the Operating Instructions under "Tube Replacement" (Section V—Maintenance).
5. All measurements should be made from the tube pin to —B (⏚) point, except where otherwise noted.
6. Variations in observed voltage readings from tabulated values do not necessarily indicate improper operation unless deviations exceed 10%.

TUBE No.	TYPE	PIN NUMBER								
		1	2	3	4	5	6	7	8	9
V-1	12AU7	170	0	7	Note 1		170	0	7	—
V-2	12AX7	90	0	1.0	Note 1		79	0	1.0	—
V-3	12AT7WA	107	0	2.0	Note 1		174	0	2.0	—
V-4	6AL5	97	97	Note 2		120	—	74	—	—
V-5	12AX7	197	97	98	Note 1		197	97	98	—
V-6	12AT7WA	155	56	57	Note 1		155	56	57	—
V-7	12AT7WA	152	41	42	Note 1		152	41	42	—
V-8	5687	235	150	154	Note 3		154	150	—	235
V-9	5687	153	33	37	Note 3		137	33	—	153
V-10	6BW4	—	305	Note 2		—	—	305	—	—
V-11	6080	200	302	235	200	302	235	Note 4		—
V-12	5751	200	87	86	Note 1		182	87	86	—
V-13	6626/ OA2WA	—	87	—	—	235	—	—	—	—

NOTES:

1. 6.3 volts a.c. measured from pins 4 and 5 to pin 9.
2. 6.3 volts a.c. measured from pin 3 to pin 4.
3. 6.3 volts a.c. measured from pins 4 and 5 to pin 8.
4. 6.3 volts a.c. measured from pin 7 to pin 8.

SCHEMATIC DIAGRAM



IMPORTANT

This equipment was thoroughly inspected and tested and was in perfect operating condition when it left our plant. Extreme care has been used in its packing. Our responsibility in regard to this shipment ended upon its delivery to the carrier. Responsibility for its safe delivery was assumed by the carrier upon acceptance of this shipment. Therefore, all claims for loss or damage sustained in transit must be made upon the carrier.

CONCEALED DAMAGE

Concealed damage means damage which is not apparent until the equipment is unpacked and examined or tested. When damage of this sort is discovered a written request for inspection must be made of the carrier's agent within 15 days of the delivery date. Contents may be damaged in transit due to rough handling even though the carton shows no evidence of external damage. Delay in making this request may give grounds for refusal of the claim. In any event the carton, packing material, wrappings, etc., must be kept available for inspection. Claim must be filed promptly with the carrier who will usually request the return of the material to our plant for inspection and repair. This equipment will then be returned to you with an invoice itemizing all repairs due to damage which becomes part of your claim.

VISIBLE LOSS OR DAMAGE

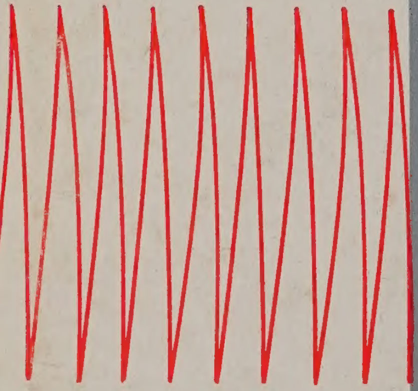
If the number of cartons received does not tally with the number or pieces shown on the freight bill or express receipt, if the weight of the shipment does not agree with the weight shown on this receipt or if there is visible evidence of damage to the shipment or its containers, these discrepancies must be noted on the waybill and signed by the carriers agent. Failure to adequately describe such external evidence of loss or damage may result in the carrier refusing to honor a damage claim.

SHIPMENTS F.O.B. DESTINATION

In the case of shipments which have been made F.O.B. destination we will be glad to handle the filing of claim for damage provided we are furnished with an acceptable inspection report from the carrier. In the event that claim is disallowed because of negligence in obtaining this report, it will be necessary for us to bill repair charges to you.

BRUSH INSTRUMENTS
DIVISION OF CLEVITE CORPORATION
37th & PERKINS CLEVELAND 14. OHIO

222640



brush INSTRUMENTS

DIVISION OF

3405 PERKINS AVENUE **CLEVITE** CORPORATION CLEVELAND 14, OHIO